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OZONE DEPLETION, THE GREENHOUSE EFFECT, AND CLIMATE CHANGE

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HEARINGS

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENTAL POLLUTION

OF THE

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS UNITED STATES SENATE

NINETY-NINTH CONGRESS

SECOND SESSION

JUNE 10 AND 11, 1986

Printed for the use of the Committee on Environment and Public Works

U.S. GOVERNMENT PRINTING OFFICE
61-732 O WASHINGTON : 1986

For sale by the Superintendent of Documents, Congressional Sales Office
U.S. Government Printing Office, Washington, DC 20402

Y4. P96/10:

61-732 O—86——1

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OZONE DEPLETION, THE GREENHOUSE EFFECT, AND CLIMATE CHANGE

TUESDAY, JUNE 10, 1986

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
SUBCOMMITTEE ON ENVIRONMENTAL POLLUTION,
Washington, DC.

The subcommittee met at 9:30 a.m., in room SD–402, Dirksen Senate Office Building, Hon. John Chafee (chairman of the subcommittee) presiding.

Present: Senators Chafee, Stafford, Symms, Mitchell, and Baucus.

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator CHAFEE. Good Morning. Today we are beginning important hearings to discuss two related problems that stem from pollution of the Earth's fragile atmosphere: there is the problem of ozone depletion; and there is the problem of the greenhouse effect and climate change.

I am pleased that we have many distinguished witnesses and delighted that all of you are willing to share your views with this committee. Several of our witnesses have traveled great distances and altered their plans to be here. We appreciate your willingness to help us.

Last December, my friends and colleagues, Senators Durenberger and Baucus held a hearing in the Subcommittee on Oversight to discuss global warming. Their attention to and interest in these matters should be recognized and commended. Our work today in the Subcommittee on Environmental Pollution is a direct result of their efforts. Similarly, the efforts of Senator Gore to focus congressional attention on the problems of the greenhouse effect are applauded.

Today's hearing will focus on the nature of the problems, including the likely timing and magnitude of predicted changes and the risks posed by such changes. Tomorrow's hearing will concentrate on what is being done by the Federal Government, both domestically and internationally, to both improve our understanding of these matters and to respond to them.

We will consider the buildup of greenhouse gases which threaten to warm the Earth to unprecedented levels. Such a warming could, within the next 50 to 75 years, produce enormous changes in a climate that has remained fairly stable for thousands of years.

We will also look at the future of the ozone layer which acts as the Earth's protective shield blocking excessive ultraviolet radiation from the Sun. From what we know today, the growing use of manmade chemicals may trigger a significant depletion or modification of the ozone layer. These two problems: the greenhouse effect and ozone depletion, are closely related.

Now, why is all of this so important? Why are we spending time on these problems?

We are doing so because there is a very real possibility that man—through ignorance or indifference, or both—is irreversibly altering the ability of our atmosphere to perform basic life support functions for the planet.

These hearings must depart from previous examinations of these problems. Ozone depletion and the greenhouse effect can no longer be treated solely as important scientific questions. They must be seen as critical problems facing the nations of the world. These are problems that demand solutions.

A recent assessment of the greenhouse problem by the Department of Energy summed up the stakes in stark terms:

> Human effects on atmospheric composition and the size and operations of the terrestrial ecosystems may yet overwhelm the life support system crafted in nature over billions of years.

This is not a matter of Chicken Little telling us the sky is falling. The scientific evidence, some of which we will hear today, is telling us we have a problem; a serious problem. There is much that we know. There is a great deal that we can predict with a fair amount of certainty.

Now, it is true that we lack the tools to close all of the scientific gaps. We don't completely understand our climate systems and we cannot predict precise outcomes. But we will always be faced with a level of uncertainty. It is a fact that the current gaps in scientific knowledge may not be closed for many years. Therefore, the question raised is this: Can we continue to risk so much when we do not know the detailed nature of the outcome?

To my mind, the risks are so great that we must avoid continuing on a path that will irreversibly alter our environment unless we know that it is safe to proceed down that path. Scientists have characterized our treatment of the greenhouse effect as a global experiment. It strikes me as a form of planetary Russian roulette.

We should not be experimenting with the Earth's life support systems until we know that—when the experiment is concluded—the results will be benign. As Russell Peterson, former chairman of the President's Council on Environmental Quality who worked as a chemist for 26 years has said "we cannot afford to give chemicals the same constitutional rights that we enjoy under the law, chemicals are not innocent until proven guilty."

By not making policy choices today, by sticking to a "wait and see" approach, we may in fact be making a passive choice. By allowing these gases to continue to build up in the atmosphere, this generation may be committing all of us to severe economic and environmental disruption without ever having decided that the value of "business as usual" is worth the risks.

Those who believe that these are problems to be dealt with by future generations are misleading themselves. Man's activities to date may have already committed us to some level of temperature change. If historical evidence is any guide, a slight warming may be enough to turn productive, temperate climates into deserts. To quote from another recent Department of Energy report, "large changes in both precipitation and the extent of deserts and grasslands can be associated with relatively small variations in the global mean temperature."

The path that society is following today is much like driving a car toward the edge of a cliff. We have a choice. We can go ahead, take no action and drive off the edge—figuring that, since the car will not hit the bottom of the canyon until our generation is already long gone, the problem of coping with what we have made inevitable, is for future generations to deal with. We can hope that they will learn how to adapt. On the other hand, we can put the brakes on now, before the car gets any closer to the edge of the cliff and before we reach a point where momentum will take us over the edge, with or without application of the brakes.

Having painted a bleak picture, the question arises: What do we do about all of this?

The first thing we should do is to ratify the Vienna Convention for the protection of the ozone layer which is pending on the Senate Calendar. The convention is the first worldwide legal instrument directed to the protection of the atmosphere as a resource. It has the support of industry, environmental groups, and the administration and should be ratified as soon as possible.

Next, it is important to focus attention on the potential effects of ozone depletion and of climate change on the choices that we as a global society must make if we are to avoid further buildup of harmful gases in the atmosphere. These are no longer just science issues. They are now policy issues.

As evidenced by the October 1985 Villach Conference, there is now an international consensus among the scientific community. Although there will always be dissenters, those who claim, for example, that the Earth is actually cooling not warming, the scientific community has told us with unusual clarity that we have a problem. We must not allow their message to fall on deaf ears.

To move us along in the right direction, I intend to ask my colleagues to join me in six new initiatives.

First, we will be asking EPA Administrator Thomas and the Executive Director of the Office of Technology Assessment, Jack Gibbons, to launch immediate and separate studies setting forth policy options that, if implemented, would stabilize the levels of atmospheric gases. These studies are expected to address significant changes in energy policy—in terms of both improvements in energy efficiency and development of alternatives to fossil fuels—reductions in the use of CFC's, ways to reduce other greenhouse gases such as methane and nitrous oxides, as well as rates of deforestation and reforestation efforts. The thought is not to embark on a 5- or 10-year study but to conclude these studies in fairly short order; say 1 or 2 years.

Second, the National Academy of Sciences will be asked to review existing gaps in scientific knowledge and to make recommendations to us on how to close these gaps. Again, this is a task that should take several months, not several years. In developing recommendations, the Academy will be expected to consult with all of the relevant Federal agencies.

Third, the Department of State should make its best effort to bring these issues to the attention of other nations. At a minimum, that effort should include discussions at the next summit meeting with the Soviet Union and at the next international economic summit meeting. The fact that the Soviet Union contains 44 percent of the world's coal reserves makes their involvement particularly important. Similarly, the vast coal reserves in the People's Republic of China makes them major players in this matter.

Fourth, we will be urging the United Nations Environment Program and the World Meteorological Organization [WMO] to expand their efforts to assess climate change problems and its social and economic impacts. As a followup to the successful Villach Conference of October 1985, we need these organizations to look at social and economic effects of climate change and policy options to reduce atmospheric pollution. Such an assessment should enable UNEP to convene a meeting to negotiate a convention on climate change in the near future.

Fifth, EPA will also be asked to coordinate a study on the environmental effects of climate change. This study should be designed to solicit the opinions of knowledgeable people throughout the country through a process that includes public hearings and meetings.

And finally, we will be asking the President's Council on Environmental Quality to issue a directive to all Federal agencies to recognize ozone depletion, the greenhouse effect, and climate change as environmental impacts that must be considered in the NEPA process.

It seems that the problems man creates for our planet are never ending. But we have found solutions for prior difficulties, and we will for these as well. What is required is for all of us to do a better job of anticipating and responding to today's new environmental warnings before they become tomorrow's environmental tragedies.

I am delighted that the ranking member of this subcommittee, Senator Mitchell, is here, and Senator, if you have a statement, now would be a good time for it.

OPENING STATEMENT OF HON. GEORGE J. MITCHELL, U.S. SENATOR FROM THE STATE OF MAINE

Senator **Mitchell**. I thank you very much, Mr. Chairman. I commend you for holding this series of hearings, and I look forward to participating with you. I apologize in advance for the fact that I will have to attend another hearing, but I do intend to review the record of testimony very carefully and to participate in tomorrow's hearing, as well.

The problem of global warming is one of immense significance. It is the most serious and more pressing than anticipated. Previously, most of the models forecasting the rate of global warming focused on the air pollutants produced by combustion of fossil fuels. More recent data suggest that trace gases may increase the rate of warming by a factor of two. This means that warming may be increasing twice as fast as previously thought.

The data produced to date suggests there may be an average increase in temperature of 1 °C since the beginning of the industrial revolution. Considering how much warmer this June has been than average, a 1 degree difference may appear to be insignificant, but an average 1 degree increase could be devastating, so the experts tell us. A 1 degree increase in the average global temperature would melt glaciers, and such melting would increase the sea level. There are uncertainties in predicting how much the sea level would increase in a particular area. In some cases, it could be an average increase of a few feet; in others, much more. For a coastal State like Maine and to other States along the coastline, such an increase would be devastating.

An average 1 degree increase in temperature could have major impacts on agriculture. This country's Midwestern breadbasket could again become a dust bowl. More heat would mean less water for crops and variations in growing seasons. It is important to keep in mind that this average increase is global in nature. It is not a national or a regional problem. If American farmers suffer for lack of water, so will farmers all over the planet. If shorelines along our coasts are flooded, so will shorelines everywhere in the world.

The enormity of this phenomenon is staggering, and we have a responsibility to limit emissions of pollutants that trap the heat in our atmosphere. As difficult, as immense, and as seemingly remote as the problem is to our daily lives, we cannot delay. There will be those who argue that more research is necessary to completely understand the phenomenon and to answer every scientific question.

As in the case of acid rain, such complete understanding will come only after we flounder in the weight of our shortsighted policies. This is one more indication that the benefits of industrialization carry with them the burden of controlling pollutants. These pollutants threaten our lakes, fish, health, and forests today in the form of acid deposition.

We will hear today that these pollutants also threaten the future of our planet, which cannot tolerate such a sudden and dramatic increase in temperature and survive in a form familiar to us.

Solutions are possible and available. The statement released at the conclusion of the Villach Conference in Austria last October addresses the common nature of some of our environmental problem. That statement said in part that:

> Climate change and sea level rises due to greenhouse gases are closely linked with other major environmental issues, such as acid deposition and threats to the Earth's ozone shield, mostly due to changes in the composition of the atmosphere by human activity.

Reduction in coal and oil use and energy conservation undertaken to reduce acid deposition will also lower concentrations of greenhouse gases. Reductions in emissions of chlorofluorocarbons will help protect the ozone layer and will also slow the rate of climate change. The rate and degree of future warming could be profoundly affected by governmental policies on energy conservation, use of fossil fuels, and the emission of some greenhouse gases.

The testimony we will hear today will demonstrate that such governmental policies are needed; nationally and on a global basis.

The testimony I expect we will hear from Federal agencies tomorrow will be that current government policy is to conduct more research, a familiar refrain from this administration on issues of this type.

What is missing in the Federal effort is action. The problem of global warming brings another round of scientists before us decrying the folly of waiting until it is too late to prevent irreversible damage. In the case of acid rain, research has been offered as a substitute for much-needed action. This policy has produced more bodies of water that cannot sustain life, more trees that are dying, and more people who find it hard to breathe.

The policy has produced more studies, not any meaningful change in policy. I hope these 2 days of hearings will help persuade the administration that inaction has its own costs, almost invariably higher than the cost of action.

I represent a State that already has been affected by acid deposition. I want to do all I can to keep Maine, the rest of our country, and our planet from facing potentially more dramatic environmental damage from global warming. The best way to avoid these undesirable outcomes is to begin taking action now to prevent further damage rather than spending twice as much time and, later, money repairing damage.

Mr. Chairman, I look forward to working with you and the other members of the committee on this issue.

Senator **Chafee**. Thank you very much, Senator Mitchell. We appreciate your interest and drive and energy in this matter and recognize that you have other commitments but look forward to you participating in these hearings to the extent you can.

[Senator Baucus' opening statement follows:]

OPENING STATEMENT OF HON. MAX BAUCUS, U.S. SENATOR FROM THE STATE OF MONTANA

Senator **Baucus**. Mr. Chairman, the subject of today's hearing presents one of the greatest challenges any of us will face.

The implications of rapid global warming has the potential to disrupt and alter life as we know it today. The changes that are being talked about are more rapid than anything that has occurred since man began to walk the face of this Earth.

The time for action is now. If the scientific community's projections of actually seeing effects within the next 20 years and almost certainly within the next 50 years are correct, then we may already be beyond the point where we have luxury of waiting to act.

The real question before us is what actions should we be taking now.

The United States as a country has slipped as a leader of environmental protection. We need to regain that leadership position.

Today air quality issues in general and acid rain in particular, finds itself mired in what seems to be insurmountable regional bickering.

This inability to act is not just a congressional problem, but it extends throughout the executive branch.

We have lost sight of the big picture.

There is an absurd assumption that we can stall and put off these tough decisions until some unknown future date.

We need to lay aside the silly arguments over the value of a fish versus cleaning up the environment and get on to the real job of protecting our home, both for current and future generations.

Everyone complains, you can't predict the weather, but overall we all expect it to be about the same, year after year.

When it does change, even for short periods of time, the disruptive effect can be tremendous.

Eastern Montana is dotted with places where people tried to farm until the dust bowl of the 1930's wiped them out. During this drought, whole communities throughout the great plains literally dried up and blew away. These changes were short-term natural occurrences.

With the "greenhouse effect," we are not talking about short-term changes.

We are talking about permanent and perhaps ongoing change for some indefinite period into the future.

Furthermore, we are not talking about localized areas being affected, but worldwide change.

What do we know about the "greenhouse effect?"

First, we debated if the question is increasing CO_2 buildup in the atmosphere.

We found that it was. We actually measured this increase.

Then, the scientific community projected that based upon this increase, there would be an increase in worldwide temperatures. The jury is still out.

Those changes may now be occurring. It is expected that within the next few years, we shall actually be able to measure these changes.

The question is, should we just wait until we actually know for sure, or take steps now to address the problem?

I come down on the side of action. We are talking about a problem that has been building up for at least since the last century.

Each day we fail to set needed policies in motion, the potential for failure increases.

Mr. Chairman, I commend you for calling this hearing to focus attention on this critical environmental problem. This is the most critical environmental problem we will face, both for the remainder of this century and well into the next century.

Senator Durenberger and I conducted a hearing on the "greenhouse effect" late last year.

This committee needs to join together to make this issue a high profile policy question and to focus needed attention both here in the United States and internationally, so that we can begin work toward solving it.

We need to educate the public.

We need to move forward with critically needed reforms to the Clean Air Act.

And, we need to accelerate the research needed to more fully understand the question. Finally, we cannot go it alone. This issue must be given international attention by every nation in the world.

The United States needs to build on initiatives it has underway and we need to gain eminence as a leader in worldwide environmental protection.

One of the first steps, that should be taken is for the President to include discussions on the "greenhouse effect" in any upcoming summits with the Soviet Union.

I look forward to working with you and every member of this committee, to ensure that this issue gets the type of attention that is needed and it deserves.

Senator **Chafee**. Senator Gore, we welcome you here. Senator Gore has taken a long interest in these matters, especially when he served in the House, and has carried those interests over to his tenure here in the Senate. So we welcome you, Senator, and look forward to your statement.

STATEMENT OF HON. ALBERT GORE, JR., U.S. SENATOR FROM THE STATE OF TENNESSEE

Senator **Gore**. Thank you very much, Mr. Chairman, Senator Mitchell. Thank you for your courtesy in inviting me to testify today. I have listened to both of the opening statements, and I think they are really excellent presentations of what the problem is that we face. I will put my prepared statement into the record with your permission and spend a short time here talking about the policy implications of this problem.

You have a distinguished roster of scientists and experts to discuss these technical issues, but as you noted, Mr. Chairman, in your opening statement, these are no longer scientific issues alone; they are policy questions that we must resolve.

As you also mentioned, I held a series of hearings over on the House side beginning 5 years ago and continuing up until I left the House. During those hearings, I was very surprised at the testimony I heard. At the beginning, the scientists were divided on the question of whether the greenhouse effect was real or not. When we first looked at it, the trend was toward seeing it as a real phenomenon.

By 1984, and certainly by the Villach Conference of last fall, the consensus had jelled. At the present time, and this is the first fact that I would like to impress on the subcommittee, and you are well aware of it, is that there is no longer any significant difference of opinion within the scientific community about the fact that the greenhouse effect is real and is already occurring.

Fact No. 2: Even if we took the most extreme actions imaginable right now, we would still feel significant impacts from the greenhouse effect, because of the momentum that has already been programmed into the world climate system.

Fact No. 3: These impacts are not the type that we should simply sit back and wait for . The temptation is, when something is this big and this powerful, to conclude, "Well, we just can't do anything about it anyway." It almost begins to climb into the category of an act of God, something that appears so overwhelming and unstoppable that we are tempted to just say, "Well, let's not even fool with that." That is particularly true when one of the suggested responses is a dramatic change in the pattern of fossil fuel consumption in the world. A change of that kind is difficult to imagine.

Because the impact is so great, we have to begin to think about what we can do to mitigate the impact of the greenhouse effect. The first choice I think we should make, therefore, is to refuse to give up and say that this is inevitable and the remedies are unthinkable and therefore, the only thing we can do is learn to live with it and adapt to it. We should choose, instead, to: One, improve the world's confidence in the knowledge of this problem so as to enhance our willingness to take the type of action that will be necessary.

We may have to begin with pieces of the problem, such as deforestation. The experts tell us that at least 20 percent of the problem, and probably more, is due to the rapid rates of deforestation in the world. It is easier, Mr. Chairman, for me to imagine a global effort at reforestation than it is to imagine a dramatic shift in fossil fuel use patterns in a comparable period of time.

Perhaps by building our confidence that we can deal with this issue on a global basis through attacking reforestation, we can then build enough momentum to make a meaningful change in fossil fuel patterns.

Similarly, the contribution of these trace gases is significant. Chlorofluorocarbons, which you have singled out on several occasions in the past, may represent one-third of the total contribution of trace gases to the greenhouse effect.

Trace gases, in turn, may amount to 40 percent of the total problem. Twenty percent of the problem is due to deforestation. The remaining 80 percent is due to the changes in the makeup of gases in the atmosphere. One-half of that is attributed to trace gases and not the carbon dioxide.

If one-third of the trace gases are chlorofluorocarbons, that is a significant percentage. Maybe we can attack that problem and then, in the process, improve the ability of the world to cope with this problem and pick up the momentum that is necessary in order to address the main part of the problem.

I believe very strongly, from a policy standpoint, that when we are dealing with an issue that is this important, and I think it will be the environmental issue for the remainder of this century, and when the remedies are so difficult and almost unthinkable, the first step has to be to increase the level of confidence that we have in the data. It is also essential to increase the level of agreement both here in the United States and in other countries about why it is necessary to move in a concerted way.

I think that the list of six proposals you outlined in your opening statement is excellent, if I may say so, Mr. Chairman. I would encourage this subcommittee to consider the addition of one more measure to that list. Earlier this year, I introduced Senate Concurrent Resolution 96, which calls for an international year of study on the greenhouse effect. I remember the International Geophysical Year in 1957 and the dramatic advances in scientific knowledge which resulted from that year of cooperation.

In fact, ironically, our best data on the increasing levels of CO_2 in the atmosphere come from experiments that were launched during the International Geophysical Year in 1957. I am sure this subcommittee is aware of the chart showing the stepwise increase in parts per million of CO_2 in the atmosphere.

This comes from the research station in Hawaii which was initiated as part of the 1957 International Geophysical Year. If we had an international year of research into the greenhouse effect, I believe it would help to quickly elevate the awareness of all nations of the importance of this problem, and it would increase our level of confidence in the data that we are working with, thereby making it more likely that we could increase our resolve to deal with this problem.

Mr. Chairman, as I mentioned, I will put my prepared statement in the record, but I would like to close by commending you for your leadership and this subcommittee for its activity in this area. I wish to work with you and cooperate in every way possible to address this incredibly important problem. Again, I thank you for your invitation to be here this morning.

Senator CHAFEE. Thank you very much, Senator Gore. It seems to me you put your finger on it. The problem is so massive that there is an inevitable reluctance on the part of anyone to really plunge in and try and do something about it. "This is really too big for us" is the reaction, I think.

We don't have all the perfect scientific evidence. There may be gaps here and there. Indeed, some suggest that the ozone situation is not depleting but is increasing, and it goes back and forth. I suppose you can find somebody who will say the world is flat. Nonetheless, I think we have got to face up to it. We can't wait for every shred of evidence to come in and be absolutely perfect; I think we ought to start along the route that you suggest to try and do something about it, and certainly, to increase the public's awareness of the problem and the feeling, as you say, that it is not hopeless. We can do things such as the reforestation that you mentioned, the other efforts with the chlorofluorocarbons, for example. We can do something. Indeed, we have done a modest amount here in the United States already.

So I hope that with your continued support and interest and that of others in the Senate, we can plunge ahead and accomplish something even though it might not be the total cure. At least we can get started on this long road, where the first step does make a difference.

Senator Stafford is here, the chairman of the full committee. We welcome you, Mr. Chairman; Senator Gore has just completed his statement. If you have any questions for him or wish to give your own statement, now would be a good time.

Senator STAFFORD. Thank you very much, Mr. Chairman. I am very happy to be here. Asking questions of a witness when I haven't heard his statement would be rather presumptuous on my part.

Senator GORE. It has been done before, Mr. Chairman.

Senator STAFFORD. I was thinking, Senator, of the celebrated Steve Allen Show many years ago when he would propound the answer and somebody would think up the question.

I apologize for not being able to get here sooner, Mr. Chairman. I do have a brief statement.

I am sure you want me to come to the first paragraph of it, because in it I say, first let me congratulate you on holding these hearings.

Senator **Chafee**. That is fine, no one will argue with that.

OPENING STATEMENT OF HON. ROBERT T. STAFFORD, U.S. SENATOR FROM THE STATE OF VERMONT

Senator **Stafford**. It seems every issue we deal with is important, but one or two of them, including this one are, I think, of surpassing importance. As important as they may be, obtaining public and press attention is devilishly difficult. Such has been the case here. In August 1979, the DuPont Corp. provided every member of this committee and its staff with a briefing book on CFC's and ozone depletion. My copy is here with me today. Even though nearly 7 years have passed, here it is. I have even learned how to pronounce chlorofluorocarbons. DuPont said, 7 years ago, we should wait for the result of 3 to 5 years of research before taking action. Adding to that, and here I quote.

> If ozone depletion is detected during this period, the wisdom of waiting out the rest of the period obviously would be reassessed.

I expect we will hear today that this is a time for reassessment, because it is my understanding that ozone has decreased, temperature has increased, the ocean is warming, glaciers are melting, and the sea level is rising. Scientists everywhere appear to be crying out to our wisdom. This issue has been plagued in the past by the unwillingness of political leaders to admit the existence of a problem, unless they see at least the glimmer of a solution.

The industry has been very effective at warning our people that air-conditioning, refrigeration, and foam insulation were all at stake in this debate. What they have not been told is that the other so-called necessities at risk are spray perfume, fresh frozen corn on the cob, and styrofoam packages for Big Macs. Mr. Chairman, please accept my sincere compliments for your political courage and willingness to conflict this important subject.

Senator **Chafee**. Thank you very much, Senator Stafford. I am delighted that you were here. Again, we thank you for coming, Senator Gore, and look forward to continuing to work with you as we proceed.

Our first panel will consist of, if you gentlemen would come to the table, Dr. Robert Watson, Director of the Upper Atmospheric Program of the National Aeronautics and Space Administration; Dr. Sherwood Rowland, professor of chemistry, University of California at Irvine, and Dr. James Hansen, the man who really started all this interest and concern about 10 years ago, I guess. Dr. James Hansen, Director, Goddard Institute of Space Studies, National Aeronautics and Space Administration.

Gentlemen, we welcome each of you here. Why don't you proceed. All of your statements will be included in the record, and if we could keep them to roughly 5 minutes, that would be fine. I am not going to drop the gavel exactly at 5 minutes, but close thereto. There will be questions, and somebody has a movie, and that won't count within the 5 minutes.

So why don't you proceed, Dr. Watson?

STATEMENT OF DR. ROBERT WATSON, DIRECTOR, UPPER ATMOSPHERIC PROGRAM, NASA

Dr. WATSON. Thank you, Mr. Chairman. Mr. Chairman, members of the subcommittee, I am pleased to be here today to talk about the issues of ozone depletion and global warming. As you yourself have already said, these are very serious issues. The main concerns, as you already pointed out, are depletion of the ozone layer, which, if depleted, could have consequences for climate, and in addition, there could be large amounts of ultraviolent radiation reaching the ground, which would have effects on human health and agriculture.

Global warming could lead to change in precipitation patterns and sea level rise. There should be no doubt today that there is compelling evidence that the composition of the atmosphere is changing at a rapid rate on a global scale. These gases are: carbon dioxide, nitrous oxide, methane, and chlorofluoromethanes. All of these changes are caused by human activities; that is, combustion and agricultural policies. However, the CFC's are of anthropogenic origin, as has been stated already, due to use in refrigeration, foam blowing, and as aerosol propellants.

These trace gases are predicted not only to modify ozone, but to change the radiative balance of the atmosphere. Therefore, we must stop thinking of these issues as isolated issues and consider them to be coupled both scientifically and politically. Policymakers should be aware that if there is a change in either the ozone layer or the climate system of the world due to either nitrous oxide or chlorofluorocarbons, full recovery of the system will take decades to centuries, because of the long atmospheric half-lifetimes of these gases.

There is a difference, however, between the ozone issue and the climate issue. Predicting changes in the column amount of ozone is difficult. The reason it is difficult is because the fluorocarbons and nitrous oxide decrease ozone, whereas methane and carbon dioxide increase ozone. Therefore, there are some compensating effects in the ozone issue. This contrasts dramatically to the global-warming issue, because all of these gases are predicted to increase the temperature of our globe. They do not compensate for each other.

The question of whether there is ozone depletion can be ascertained using a simple formula. If the growth in CFC's exceed the growth of methane and CO_2, there will, indeed, be a decrease in the atmosphere concentration of ozone. If, however, the rate of growth of methane and CO_2 is larger than the rate of growth of CFC's, there may be no change in the total amount of atmospheric ozone over the next century.

A simple calculation would say that if methane and CO_2 continue to increase at their current rates of 1 percent and half a percent a year, respectively, and the CFC's increase at 3 percent a year, we could expect a 10-percent ozone depletion in the next 70 years and increasing drastically thereafter.

From the two dimensional models, we can see that these effects will not be constant with latitude. There will be less depletion at the equator but much larger depletions in the polar regions. We should note, however, that even when there are only small changes in the column content of ozone, we would still anticipate a significant change in the vertical distribution of ozone. This could cause a serious change in the climate system.

One other question that has been asked this morning is has ozone changed? There does seem to be evidence that the ozone has changed at 40 kilometers. This is quite consistent with the fluorocarbon theory. However, there doesn't seem to be evidence that the total column amount of ozone is changing on a global scale from the Dobson network. However, we would not expect to have seen large changes in ozone in the last 10 or 15 years.

There is some preliminary evidence from satellite data from NASA that has shown that the column of ozone and vertical distribution may have changed over the last 5 to 10 years. This data awaits further analysis.

One thing I will show you in a few minutes, hopefully, is a film on ozone, and here we will see that there has been huge, unexpected changes in Antarctic ozone in the springtime. We do not understand what the processes are that are causing the changes in the Antarctic ozone. Until we understand these processes, we will not be able to say with any real confidence what the implications are for the global system.

Another key question is: How reliable are the theoretical models? Unfortunately you can't have a true test of the predictive capability of a model. All you can do is use a model to describe today's atmosphere and compare it to atmospheric observations. In general, there is good agreement between atmospheric observations and the models.

However, there are some disagreements in detail which limits our confidence in the predictive capability of each model. I would only like to make a couple of minor comments with respect to climate, as Dr. Hansen will cover this in great detail.

I would like to summarize the statement simply by saying there are models that have predicted somewhere between a one-third and 1 degree change in the last 100 years. This is quite consistent with atmospheric observations which suggest at least a half a degree rise over that time period. Most of that has been contributed by CO_2.

What is likely to happen in the future? Here is a possibility. As we have already heard today, the trace gases, methane, nitrous oxide, and fluorocarbons, are thought to contribute equally, if not greater, to the predicted global warming relative to CO_2. We predict the rates of global warming will be a factor of 3 to 10 times faster in the next 50 years than the last 100 years, and so we can expect significant changes in climate in the next few decades.

In summary, I think we have to say the global change and warming trend has doubled. It is not wise to experiment on the planet Earth by allowing the concentrations of these trace gases to increase without full understanding of the consequences.

Thank you, Mr. Chairman, and I am willing to show this film at your convenience.

Senator **Chafee**. Before we show the film, I would like to get you to explain a little bit about this. I have seen the film, and if you see it for the first time, you are a little confused. Where the hairs cross at the center, I assume that that is the South Pole; is that correct?

Dr. **Watson**. Correct. It is a bird's eye view of our Earth from the satellite looking down on the South Pole, so what it is, is a polar stereographic projection of the Earth; the South Pole is in the center, and the Equator is around the edge.

Senator **Chafee**. You will see a constant movement clockwise, and that is the prevailing winds circulating around?

Dr. **Watson**. That is correct. It is the basic meteorology, and what it is called is a polar vortex. What you see is that the air is trapped over the South Pole, and it goes around in a circular motion.

Senator **Chafee**. The red we see will be the enlargement of the so-called ozone hole?

Dr. **Watson**. Actually, the color scheme on this particular plot is probably different from what you have seen before, but I can walk you through it. What you will be seeing is every day in October from 1979 through 1985. The two things to notice is over the Antarctic Continent, ozone has dropped about 30-to 40-percent from 1979 to 1985. But what we also noticed by carefully examining the data in the last year is there has also been a decrease in ozone from 50 degrees south and 70 degrees south.

We originally thought it was confined to the Antarctic. We can now see that the depletion has expanded to 50 degrees south. We haven't seen it in other parts of the globe yet. We haven't seen it in the Arctic. You will see changes in color which represent changes in ozone. You will see, typically, a 30- to 40-percent change in ozone over the last few years' time period.

Senator **Chafee**. The picture that we see is a model, is it not? Is it actually taken from a satellite?

Dr. **Watson**. Yes. This is actual data measured from the nimbus 7 total ozone monitoring system, nothing to do with theory.

Senator **Chafee**. The actual picture, is that a picture that is taken, or is this a model that you have made based on the data that you gathered?

Dr. **Watson**. It is a model of the data. It is a simulation of the data to make it pictorial.

Senator **Stafford**. Mr. Chairman, maybe this will be answered later on in testimony, but before we see the picture, I think it would be interesting if we knew from the scientists here what ozone is and how is it formed, as well. I think we have some basic idea of why it is important, but my recollection is that one source is from automobile exhaust, hydrocarbons, and sunlight, but maybe I am wrong about that. Maybe a brief explanation of what it is and why it is important would help us in the total picture.

Dr. **Watson**. Yes. A simple explanation is that most of the Earth's atmosphere, as we know, is made up of molecular oxygen and molecular nitrogen. When ultraviolet radiation inpinges on the Earth's atmosphere, it dissociates molecular oxygen into two oxygen atoms. Thus, it produces ozone (03). The importance of 03 is that it absorbs solar radiation of wavelengths less than 300 nanometers. The reason that this is important is that wavelengths of 300 nanometers or less can have an adverse effect on ecology. It produces skin cancer; it can change aquatic and terrestrial ecosystem productivity. So ozone acts as a filter that shields out harmful ultraviolet radiation from reaching the Earth. Changes in ozone could change the penetration of ultraviolet radiation through the atmosphere.

In addition ozone controls the temperature of the stratosphere. It is very important to the radiative balance of the stratosphere. Therefore, the predominant reasons why ozone is important are climate and changes in ultraviolent radiation. What we worry about here is putting trace concentrations of chlorine and nitrogen gases in the atmosphere. They change the rate at which we destroy ozone. Ozone is naturally produced and destroyed. Addition of fluorocarbons and nitrous oxide can increase the rate at which we destroy it.

Senator STAFFORD. Is it possible to have an excessive amount of ozone at the level of the Earth's atmosphere near the ground and the depleted situation in the upper atmosphere?

Dr. WATSON. The answer is definitely yes. What we think is probably happening is that as we add chlorine and methane to the atmosphere chlorine is causing the ozone near 40 kilometers to decrease, but the methane is increasing ozone near the ground. That is one of the reasons why under certain scenarios in the future composition of the atmosphere, there may be no change in the total column of ozone, but changes in the vertical distribution which may have consequences for ecosystems and climate.

Senator STAFFORD. And depletion up high.

Senator CHAFEE. We are delighted that Senator Baucus has joined us. Senator, if you have a statement you would like to deliver or make now, this would be a good chance.

Senator BAUCUS. Thank you, Mr. Chairman. I have a statement that I will submit for the record and take a minute to say that I am here, as all the rest of us are here, because we are very concerned about the problems. It is very clear to me that the greenhouse effect is much more severe and the results are much more severe than I think most people have earlier anticipated.

The results are probably going to visit us on this planet much more quickly than many of us had earlier anticipated, and I think it is encumbent upon all of us to try to better determine what those potential changes might be.

It is very important to better determine what we should do about it. I think it is a very important hearing, and I want to commend you for holding it. It is absolutely critical. I thank you.

Senator CHAFEE. Thank you very much, Senator.Your statement will be included in the record following the other opening statements.

Are there any other questions before we proceed with the movie? It is about a 2- or 3-minute movie, I think.

Dr. WATSON. That is correct.

Senator CHAFEE. Speak up, Dr. Watson, as we go along.

Dr. WATSON. What we will see is, this is in 1979. You will see successive days in October. The center of the picture is the center of the Antarctic, the South Pole. What you can see is the ozone is moving around in a clockwise rotation. Over the Antarctic Continent in 1979, the average ozone is about 225 Dobson units. In 1980, if you look at the Antarctic, the large and lighter blue represents ozone. That is about 225 Dobson units.

If you look around the outside, you will see the dark red color. These represent ozone concentrations of 450 Dobson units. 1981 wasn't very different from 1980. You see in the middle, over the South Pole, the ozone is typically 225 Dobson units, and that between 50 degrees and 70 degrees south, ozone is typically averaging 400 to 450 Dobson units.

In 1982, in the very center of the picture for the first time, you see some slight pink color. This is where the ozone has now decreased to around 200 Dobson units. It only comes in periodially, just flashing on and off. Nothing much else is happening on the outer regions between 50 south and 70 south.

In 1983, if you look over the South Pole, now the pink region is definitely much larger, and you even see regions where it is lower than that. So you see numbers more like 180 Dobson units at this point. So you have seen that from 1979 through 1983, over the South Pole, the ozone has decreased from about 225 down to about 180 Dobson units.

By 1984, that pink color is much, much broader. It represents a much wider geographic area. We are even seeing much more of the mixed shade, sort of a mauve color coming in, which is on the order of 160 Dobson units. Around the outside, between 50 south and 70 south, it appears the ozone has decreased to 400 Dobson units.

In 1985, you can see that on average, the ozone is as low as 150 Dobson units over the South Pole, the very dark purples, and at the outside, we no longer get the deep reds between 50 south and 70 south, which represents about 450 Dobson units. "End of penguins?" That is a good question.

Fundamentally, ozone has decreased typically about 30 to 40 percent over the last 7 years. We don't understand why. It was totally unexpected. There are quite a number of theories that have already been postulated. It is going to take at least several years to disprove or get more confidence in some of these theories.

Senator **Chafee**. Thank you, Dr. Watson. We will ask questions after we hear from each member of the panel. Next, we will hear from Dr. Sherwood Rowland, professor of chemistry, University of California at Irvine.

Dr. Rowland, with Dr. Molina, published the original paper some 12 years ago setting forth the concerns that arise from chlorofluorocarbons and the whole problem of the ozone depletion. So we welcome you, Dr. Rowland.

STATEMENT OF DR. SHERWOOD ROWLAND, PROFESSOR OF CHEMISTRY, UNIVERSITY OF CALIFORNIA, IRVINE

Dr. Rowland. Thank you, Senator, for inviting me to present my summary.

The first paper which Dr. Molina and I published in June 1974 carried the outline of our theory that the chlorofluorocarbon gases would eventually produce serious depletion in stratospheric ozone and was summarized by the following abstract:

Chlorofluoromethanes are being added to the environment in steadily increasing amounts. These compounds are chemically inert and may remain in the atmosphere for 40 to 150 years, and concentrations can be expected to reach 10 to 30 times present levels. Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms and leads to the destruction of atmosphere ozone.

These sentences can, with the benefit of 12 years of intensive study, now serve equally well as a brief summary of the facts of the chlorofluorocarbon-ozone problem.

If I look at the first sentence, "Chlorofluorocarbons are being added to the environment in steadily increasing amounts," that was certainly true in the early 1970's. We have had a period of a decade or so in which the release has been more or less flat, but emissions have started to increase again as uses have developed in the United States and in the rest of the world.

The second sentence says, "The compounds are chemically inert and may remain in the atmosphere for 40 to 150 years." For chlorofluorocarbon 11, the best estimate of its lifetime is now that it is about 60 or 70 years, and that for chlorofluorocarbon 12 is that the lifetime is over 100 years. That is certainly true, and you heard it in Bob Watson's testimony that the lifetimes are long. Whatever consequences we have from the chlorofluorocarbons will be with us not only at the end of this century, but at the end of the next century, as well.

The final sentence says, "Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms and leads to the destruction of stratospheric ozone."

You also heard from Bob Watson that ozone depletion has been seen in the upper stratosphere, which has, for 10 years, been the location where we have expected such depletion to be seen first.

I have a longer statement, and I am not going to go through all of it. But I do want to make certain comments that are taken from it. Basically, I want to mention several things which have come up that I think are important since the first considerations 10 to 12 years ago. These four are the following: One is that the atmosphere is a changing complex mixture of gases, and that is certainly true. At the time, in 1974, we knew only that carbon dioxide was increasing. Now we know that carbon dioxide and methane and nitrous oxide and chlorofluorocarbons and maybe some others are also increasing. So atmospheric change is a very complex problem that we have to consider.

Of course, there is only one atmosphere, so there is only one solution to the scientific problem as to what will happen when we add all of these trace gases, and that is the solution that we are going to have to live in.

The second comment has to do with the role of heterogeneous reactions in the atmosphere. About 2 years ago, my research group began investigating the possibility that some of the atmospheric components might be undergoing reactions on the surfaces of particles which are in the atmosphere. I point this out because the atmospheric models up through 1985 have been characterized by considering only reactions that take place in the gas phase. The reason that we have been considering only those reactions is that those are the only reactions that we know to be important.

But in the last several years, there are a number of things which have happened which make me believe that it is very likely that heterogeneous reactions, that is, reactions occurring on the surfaces of particles in the stratosphere, may also be contributing. I will only mention that chlorine nitrate, one of the compounds formed in the atmosphere after the decomposition of chlorofluorocarbons, is quite likely, in the atmosphere, to react with water and with hydrogen chloride.

If reactions of that kind are put into the atmospheric models, then it is possible to show that one might expect very large depletions of ozone in the Antarctic as seen in the Antarctic ozone hole. That is merely one of the theories which is floating around now in trying to explain the Antarctic ozone hole, but it is an explanation, after the fact, but plausible.

We can account for the Antarctic ozone hole, but we haven't proven that this theory is correct. We know the hole is there, and it is getting deeper every year. The third point to make is about this Antarctic ozone depletion. It is unexpected, and therefore, it means that you have to be very careful about any conclusion that you draw from your modeling, because the models did not predict it. We are in an uncharted territory as far as knowing whether we can accept any predictions if they haven't accounted for the existence of the Antarctic ozone hole.

Let me then just conclude in the following way: The Antarctic ozone hole has arrived as a profound shock, first because the losses of ozone are massive; and second, because it was completely unpredicted. Instead of the unexpected acting to ameliorate ozone depletion, it has produced huge losses. We are now in the position of having chosen to tolerate some unspecified amount of ozone depletion, and are now wondering how badly we have miscalculated.

We now have a hole in the ozone layer which will last for a century or more. Even if the entire world were to stop further emissions of chlorofluorocarbons today, which is, of course, impossible. Will the Antarctic hole deepen? Will it spread, and how soon, to other latitudes in both hemispheres? Can we afford to go for another 5 or 10 years of wait and see, of measuring and monitoring and studying?

If our prime concern is the atmosphere, the ozone layer, and the people it shields, the obvious answer is to discontinue this experiment without waiting for all of the answers. Thank you.

Senator **Chafee**. Thank you very much, Professor Rowland. Now we will hear from Dr. Hansen from the Goddard Institute for Space Studies. Dr. Hansen?

STATEMENT OF DR. JAMES HANSEN, DIRECTOR, GODDARD INSTITUTE FOR SPACE STUDIES, NASA

Dr. **Hansen**. Thank you, Mr. Chairman. In my brief summary this morning, I cannot describe the capabilities and limitations of climate models in detail. But let me just say a few words about that before turning to predictions of where our climate is heading.

Global climate models involve numerical computer simulations of fundamental equations which describe the structure and motions of the atmosphere and the oceans. These models can realistically simulate many climate variables, such as temperature, winds, and storm tracks, including the variations of these from season to season, from latitude to latitude, and from continent to ocean.

But they cannot yet accurately portray other climate variables such as regional patterns of precipitation, ocean currents, and a number of other important climate processes. But I believe that climate models are good enough now to give us some strong indications about the nature of climate changes which will occur because of the increasing CO_2 and trace gases, although a number of qualifications and caveats must accompany the results, especially for the regional and the local scales, as is discussed in my written testimony.

I will not discuss in detail the tests of the climate models in the greenhouse theory, but there are many. For example, by comparing the temperatures of different planets which have different amounts of greenhouse gases, by looking at how the Earth's temperature has changed in the past few hundred thousand years as the amount of CO_2 has fluctuated, and by looking at how much the Earth has warmed up in the past 100 years as CO_2 has increased, from all of these, we get some empirical evidence about climate sensitivity.

This empirical evidence suggests that the sensitivity of the climate system is somewhere between 2 °C and 5 °C, for a doubling of atmospheric carbon dioxide.

If Dr. Watson can help me with a couple of Vu-Graphs, I would like to show some climate model projections for how the temperature might change in the near future. These are the first GCM, global climate model, projections of the year-by-year climate change which is expected to result from the gradual growth of atmospheric CO_2 and trace gases, which is observed to be occurring now.

Senator **Chafee**. Don't go too fast. Let's make sure we understand what is what in these. What are you showing here?

Dr. **Hansen**. Let me say, first of all, these calculations were carried out by the Climate Modeling Group at the Goddard Institute for Space Studies. The model simulation begins in 1958, when CO_2 began to be measured accurately, and the model includes climate forcing due to measured changes in CO_2, trace gases, and stratospheric aerosols for the period from 1958 to 1985.

For the future, we assume two scenarios. In scenario A, we used the current growth rates for CO_2 and trace gases. In scenario B, we used growth rates which drop off rapidly as we go into the future. This map shows the global warming in scenario A; that is, for the current growth rates of CO_2 and trace gases.

This map shows the global warming in the 1990's as compared to 1958. The scale for the warming is shown on the left-hand side. You can see that the warming in most of the United States is about ½ °C to 1 °C, the patched green color. You cannot trust the detailed geographical patterns of this predicted warming because of natural climate variability. In fact, if you run the model twice, the detailed patterns will change from one run to another. But note that there are similar warmings, warmings of similar magnitude, at other regions at the same latitude as the United States.

So the magnitude of the warming is a firm model prediction, given the assumptions that are in the model. A principal assumption is that the sensitivity of the climate system is 4 °C for doubled CO_2.

Senator CHAFEE. Wait; let's finish this graph. What is the green? How many degrees in change?

Dr. HANSEN. The dark green that cuts across the United States and southern Canada, that is a warming of between 1 and 1.5 °C, which would be between 2 and 3 °F.

Senator CHAFEE. What about the yellow?

Dr. HANSEN. The small yellow piece that you see in the United States would be between 1.5 and 2 °C. In the region of the Arctic and in the Antarctic, regions of sea ice, that brighter yellow is between 2 to 3 °C, which would be about 4 to 5 °F.

Now, if we go a little further into the future, the next viewgraph shows the decade from 2010 to 2020; that is 30 years from now.

Senator CHAFEE. That is provided nothing has changed.

Dr. HANSEN. That assumes we have continued growth of trace gases and CO_2 at the rates that are occurring today.

Senator STAFFORD. Does that indicate that there will be a significant change in the temperature in both the North and South Pole areas?

Dr. HANSEN. That is right. In the region of the United States, the warming, 30 years from now is about 1½ °C, which is about 3 °F. At high latitudes the warming is as large as 4 °C.

Senator STAFFORD. What would the effect of the change be on the Arctic icepack and the Antarctic glaciers?

Dr. HANSEN. That represents two separate questions which require different answers. With regard to the sea ice, you can see that the largest predicted warming is in the regions of the sea ice. We expect the area of sea ice decrease substantially. In fact, there is some evidence that it is already occurring. If you compare the evidence for sea ice coverage in the 1930's with recent sea ice coverage, there has been a substantial decrease in the area.

It is more difficult to say how much effect this warming will have on ice sheets, how much melting of ice there will be, and how much sea level will change. The warming should increase melting on the fringes of the ice sheet, but it is also expected to increase the accumulation of snow on the interior of the ice sheets. So the effect of the warming on Antarctic glaciers is a difficult question, especially for the next few decades, when the warming is still only a few degrees. As you go several more decades into the future, the effect becomes larger.

The next Vu-Graph shows the global warming for doubled carbon dioxide. This is the equilibrium response of the model to doubled CO_2. If CO_2 and trace gases continue to increase at current rates, then the equivalent of doubled CO_2 forcing will occur approximately in the late 2020's. Because of the thermal inertia of the ocean, the climate response may be delayed by two or three decades. So this degree of warming might be relevant to about the year 2050, 65 years from now.

This warming is about 5 °C in the United States, or about 9 °F. I remind you that this scenario assumes that current growth rates for CO_2 and trace gases will continue. It also assumes that the climate sensitivity is about 4 °C for doubled CO_2. That sensitivity is uncertain by about a factor of 2.

If I have time to show another figure, I would like to show what I think is the most exciting aspect of the climate modeling results.

This is an estimate of when the greenhouse warming should begin to rise above the noise level; that is, the level of natural climate variability. The red line is the observed global temperature trend. And the red and blue lines are the modeled global temperature trends for the two scenarios, A and B.

You can see from the upper part of the figure that from 1958, when the simulations began, until the present, any trends in the real world or the model are still small compared to the natural variability of the global temperature averaged over a season.

Even if the temperatures are averaged over 5 years to reduce the noise, as we have done in the lower figure, the signal is still small compared to the natural variability of 5-year timeframe. But the exciting thing is that by the 1990's the expected warming rises above the noise level. In fact, the model shows that in 20 years, the global warming should reach about 1 °C, which would be the warmest that the Earth has been in the last 100,000 years.

I have one more graph which gives our best estimate in response to a question which you asked, Mr. Chairman, in your letter to me. You requested that we try to estimate how the greenhouse warming may be felt in U.S. cities such as Washington, DC. This is a hard question, because the global climate models are not designed for local studies. But by looking at the climatology of some particular cities in recent decades and adding on the warming from the climate models, we can get some estimates.

For example, in the top part of the figure, we show the number of days when the temperature exceeds 100 °F in Washington, DC, on the right and in Omaha, NE on the left. With the climate of the past few decades, that has been about 1 day per year in Washington, slightly less than 1 day per year, and about 3 days per year in Omaha. With the doubled CO_2 climate, which, as I mentioned, would be about 65 years in the future, if greenhouse gases continue to increase as they are now, at current rates, there would be 12 days per year of temperatures exceeding 100 degrees in Washington, and about 20 days per year in Omaha.

For temperatures exceeding 90 degrees, the number of days per year would increase from about 35 to 85 to in both cities. That is shown in the middle figure. The lower figure shows that the number of days in which the minimum temperature does not go below 80 degrees at night is estimated to increase from less than 1 day per year to 19 days in Washington and 9 days in Omaha.

So my conclusion in that the temperature changes themselves have an important effect on the climatic environment. It is not just a question of how much sea level is going to change or whether there are going to be droughts in the Midwest. I think the temperature changes themselves will be significant.

The bottom line which I would like to emphasize is that during the next decade, when we expect the greenhouse effect to clearly emerge, it is very important that we obtain global observations of the climate system.

The needed observations of the oceans, atmosphere, and the land have been described by prestigious groups such as the Earth System Sciences Committee. So I won't describe the needed observations here, but I emphasize that in order to understand the climate system better and predict future climate better, we need to have a substantial number of observations on a global scale.

Senator **CHAFEE**. I would like to ask a question of each of the panelists. That is: Do any of you believe that we need more scientific data before we could reach the conclusion that what is taking place now, if continued, will increase the temperature on the globe?

Are you prepared to say that if we keep going on the path we are now, the temperature in the world is going to increase?

Dr. **HANSEN**. I don't think we need more evidence to say that. But to answer the kind of detailed questions which are certainly going to be raised, we do need more evidence. As I mentioned global climate sensitivity is uncertain by about a factor of 2. The magnitude of the results which I showed would be different if climate sensitivity is larger or smaller than I assumed.

But I think the fact that the greenhouse effect is real is proven in a number of different ways, such as by looking at other planets, which have different amounts of greenhouse gases.

Senator **CHAFEE**. Let me get the answers from the others. Dr. Rowland?

Dr. **ROWLAND**. If you look at this Earth from satellites outside the Earth, you can see the greenhouse effect in operation at all times. If you are going over the Sahara Desert, there are transparent regions of the infrared where the radiation comes right up from the desert, and there are other regions where the radiation is only coming from the top of the stratosphere because the carbon dioxide has absorbed the radiation from the desert below that.

The fact that the greenhouse effect is working on the Earth, it seems to me, is perfectly straightforward. It has raised the temperature of the Earth about 30 degrees over what it would be without an atmosphere, and what we are talking about now are changes of another 1 or 2 or 3 degrees compared with a very large change that has already happened from gases that exist naturally.

Senator **CHAFEE**. Dr. Watson?

Dr. **WATSON**. No; I believe global warming is inevitable. It is only a question of the magnitude and the timing.

Senator **CHAFEE**. In speaking about ozone, Dr. Watson, you indicated that there were some gases that, if released, act as a neutralization of the depletion of the ozone; in other words, there are certain things that can happen to increase the amount of ozone. Would that be true no matter what layer you are at, stratosphere or whatever layer you are at?

Dr. **WATSON**. No. If you add fluorocarbons or nitrous oxide, they would tend to change ozone, deplete ozone, throughout the middle and upper stratosphere.

If you add methane, you would tend to increase ozone in the troposphere. If you add CO_2, it will produce ozone in the middle and upper stratosphere and tend to offset the chlorine. What you tend to have is offsetting effects. That is why it is much more difficult to calculate accurately how the amount of ozone will change with time.

As I said in my testimony, even if the total column doesn't change much, we would expect to see a significant change in the vertical distribution. Certain areas would have increased ozone. Other areas would have decreased ozone.

Senator CHAFEE. What if we said: This is very serious business, this loss to the ozone, so let's proceed to neutralize the depletion in some fashion. We will depend on the scientists to tell us at what altitude it should be changed and then we proceed to change it. What would be the side effects of that?

Would the side effects be worse than if we left well enough alone or bad enough alone? That is for you, Dr. Watson.

Dr. WATSON. I appreciate it.

Any change in the the column of ozone could clearly be detrimental. Any policies that you enact are clearly going to be less than adequate unless you simultaneously have a policy that controls the atmospheric concentrations of CO_2, nitrous oxide, fluorocarbons, and methane. You will be doing your own experiment. It will stop certain uses of gases and still the system will be changing.

I think one has to say that the most important factor appears to me is the total column of ozone. If you change that, decrease it, you will have more ultraviolet rays at the Earth's surface. If you change the ozone distribution, it may affect climate. But relative to the direct greenhouse affects of CO_2, CFC's, and CH_4, the impact of ozone change on the climate system is not a large effect. It may be 10 to 20 percent of the signal. The most important region is just around the tropopause, which is between 10 and 20 kilometers above the Earth's surface.

Changes in ozone around 40 kilometers don't have much impact on the temperature of the surface of the Earth; once more, the policy should try to conserve the total amount of ozone above the Earth's surface.

Senator CHAFEE. Do you agree with that, Dr. Rowland?

Dr. ROWLAND. Not entirely; no. First, let me make a comment that if you have a program to replace ozone in the atmosphere, then you are starting a scientific program which is going to make SDI look very simple.

The present amount of ozone that we have in the stratosphere is created by ultraviolet energy of the Sun that is absorbed in the atmosphere going into the production of ozone. It is going to be very hard to devise an engineering scheme that is going to compete with that. That is a serious comment. Trying to replace ozone in the upper stratosphere is essentially beyond the possibility of man.

I think some of the aspects of the question of total global ozone need to be broken down. It is not good for those of us who live in or near Los Angeles to have ozone in the troposphere; that is, down near the ground. It will not be good for more and more people of the Earth to have an increase of ozone near the surface, because it is generally deleterious to biological species.

Calculations which suggest that because we are putting in methane and that is causing an increase in ozone down near the surface do not necessarily promise a good future. It means that we are going to experience a different kind of ozone problem. But there is another question that comes up, too, with the two dimensional atmospheric models; that is, where you start considering ozone depletion as a function of distance from the Equator. As Bob Watson has said in his testimony, these models don't seem to indicate quite the same results that you get if you just look at the one dimensional model.

There is a tendency to have ozone loss over the temperate regions in the upper stratosphere and to make. to create ozone in the troposphere over the tropic regions. I am not one who is going to say that a loss of ozone over the United States or Western Europe is balanced by a gain of ozone over Brazil and India. I think those are two separate problems. They are not balancing one another off. That is the general direction that the two dimensional models are indicating that we are going.

Senator CHAFEE. My time is up. Senator Stafford?

Senator STAFFORD. Thank you, Mr. Chairman. I have found this a fascinating hearing thus far. I guess, gentlemen, we are talking about two different things: ozone depletion and its effect in relation to ultraviolet radiation, I suppose, in living animals and CO_2, and the greenhouse effect which that might cause.

There has been some evidence in front of this committee that ozone may be one of the villains in what we refer to as clean air and acid rain, that it may be attacking plant life, leafs of plants and trees. So I would gather that ozone, at the first few thousand feet of the atmosphere, is likely to turn out to be a dangerous bit of chemistry for plant life and maybe for human beings as well. Am I correct in that?

Dr. WATSON. Yes; most definitely.

Dr. ROWLAND. Yes.

Senator STAFFORD. But in the upper atmosphere, in the stratosphere, it protects us from ultraviolent light. Therefore, it is desirable up there. Of course, my first question has to be: Is there any way that we can move excessive ozone from the first couple of thousand feet of the atmosphere to the stratosphere, and I gather there probably isn't, that you know of now, anyway.

Dr. ROWLAND. There is no way that you can do it. The amount of ozone that is in the stratosphere is very much larger than the amount of ozone that is in the troposphere. About 90 percent of all the ozone is in the stratosphere, but moving something from the troposphere to the stratosphere is very difficult.

Senator STAFFORD. The ozone in the upper atmosphere is created by the forces of nature, I gather, whereas at the level of Earth, we may be contributing to it through the consumption of fossil fuels and the byproductions that come out of exhaust pipes and smokestacks.

Could I ask, do volcanic eruptions contribute to either the creation of ozone or the presence of carbon dioxide in the atmosphere in some material way that is significant?

Dr. WATSON. It was clear that after the El Chichon eruption, which was the largest volcanic eruption this century, that the ozone levels were the lowest we have seen in this century. We don't fully understand what the impact of the volcanic eruption was on the ozone, but it did appear to decrease. It may be heterogeneous chemistry, but if it does anything, it would tend to reduce ozone as part of the natural fluctuations. Volcanic eruptions have insignificant effects on CO_2 levels.

Senator **Stafford**. I see Dr. Rowland nodding.

Dr. **Rowland**. Yes; I agree with him on that.

Senator **Stafford**. In connection with CO_2, if we assume that the Earth's rising temperature maybe harmful in the long run to human and animal and plant habitation, then we have to decide whether or not we should burn fossil fuels in the very large quantities we do today, or at least find some way to burn them without putting CO_2 in the atmosphere. Is that what we are going to have to look at?

Dr. **Hansen**. Well, CO_2 is providing about half of the greenhouse warming, which we illustrated. So if you wanted to make a large reduction in that degree of warming, you would have to cut down on CO_2 emissions.

Senator **Stafford**. A principal source of CO_2, has to be the consumption of fossil fuels around the world.

Dr. **Hansen**. That's right.

Senator **Stafford**. Or manufacturing or heating, generating electricity or driving motor vehicles and others; am I correct in that?

Dr. **Hansen**. That is correct; yes.

Senator **Stafford**. Finally, from this Senator, I gather a principal source of CFC's is air-conditioning and refrigeration, which we will want more then than we do now. So my question is: Has science discovered any other substance that is less harmful to upper atmosphere ozone that could be used in place of CFC's?

Dr. **Rowland**. I would say the answer is yes. The question of air-conditioning I can use as an example.

Senator **Stafford**. Sure.

Dr. **Rowland**. You have two questions, really, in air-conditioning. One is: How do you air-condition your home, and one is, how do you air-condition your car? Chemically, the answer is different for those two. The air-conditioner for your car uses fluorocarbon 12, which is one of the prime suspects for ozone depletion. The air-conditioner in your home uses fluorocarbon 22, which is perhaps a factor of 10 less of a threat to the ozone. One of the possibilities that one could move toward would be the substitution of fluorocarbon 22 for fluorocarbon 12 in refrigeration and air-conditioning.

But in addition to that, there is another compound, fluorocarbon 134, which has no chlorine at all, and in addition, has hydrogen, so that most of it will be removed by chemical reactions in the lower atmosphere. This fluorocarbon 134 has been investigated by the British and by the United States and by the Japanese, and they find that it makes a successful refrigerant but that it would be more expensive to produce. The estimates that I have heard for how expensive it is are a factor of 5 or 10. If the cost of the fluorocarbon in a refrigerator is about $1 and the refrigerator itself would cost $500 or $1,000, then an increase in the refrigerant cost to $10 doesn't make me think people will give up buying refrigerators. Thank you very much.

Thank you, Mr. Chairman.

Senator **Chafee**. Thank you. Senator Baucus.

Senator **Baucus**. I guess you, Dr. Hansen, put the climate changes up on the screen and you predicted that the average temperature would rise, say, 2 or 3 °F. I take it those are yearly averages. My question goes to: That about seasonal variations? That is, are the winters warmer than the summers are warmer or not?

Dr. **Hansen**. The warming tends to be larger in the winter than in the summer. However, as I showed with figures for particular cities, even though the warming is somewhat smaller in the summer than in the winter, it still is very substantial, even in the summer.

Senator **Baucus**. The warming variation is greater in the winter rather than the summer because winters are colder; is that the reason? Or what is the reason, do you suppose?

Dr. **Hansen**. The principal reason is that the troposphere is highly convective in the summer, but as you warm up the atmosphere, you add more water vapor to the atmosphere; this is a greenhouse gas itself. This process is more effective at the colder temperature than it is at the warmer temperatures.

Senator **Baucus**. I don't understand why the ozone hole is in Antarctica. Why is the ozone depletion seemingly there and not, say, in the Arctic, where, theoretically, there are more fluorocarbons from aerosol cans and air-conditioners and so forth in the Northern Hemisphere as opposed to the Southern Hemisphere? Why don't we have the ozone hole in the Arctic?

Dr. **Rowland**. Let me answer that. Although the use of the chlorofluorocarbons is primarily in the Northern Hemisphere, gases that have long lifetimes, such as these gases do, spread over the entire Earth. At the present time, if you were to take an atmospheric sample, say, in Alaska and take one at the southern tip of New Zealand and compare them, they would have only about 10 percent difference in the amounts of the chlorofluorocarbons.

In fact, I have a man in Alaska today and a man on his way to New Zealand to collect air samples. That is the kind of measurement that we are making on a regular basis. So we see not only that the chlorofluorocarbons are going up steadily, but that they are spread over the entire Earth.

Either Bob or I could answer the question. I will let Bob take it.

Dr. **Watson**. It is a good question. Why do we see changes in the Antarctic but not above the Arctic? We don't fully understand why ozone is changing over the Antarctic, but some of the theories postulate that the geophysical conditions over the Antarctic are very different than at other places over the globe. It is the coldest atmosphere on the globe. It is much colder over the Antarctic than it is over the Arctic. You have air trapped in a circular motion, called a polar vortex.

The very cold temperatures give rise to very high concentrations of polar stratospheric clouds; that is, ice crystals in the stratosphere. Some theories postulate that what is happening is that all the nitrogen compounds are being converted into the form of nitric acid, so they can't react with ozone or chlorine gases, whereas the chlorine compounds are being converted into a form which can destroy ozone. The ice crystals are setting up a chemistry which is almost unique in the globe and can only happen over the Antarctic.

You can't have it over the Arctic or other regions. We think the very cold temperatures which give you the ice crystals change the nitrogen and chlorine chemistries which are normally homogeneous to the heterogeneous chemistry. When sunlight comes up in polar springtime, which is August 21, you suddenly have a very active stewpot of chemistry that leads to the destruction of ozone. That is one theory.

Other scientists postulate that the decrease in Antarctic ozone is part of a natural cycle. We have a series of theories, all of which are plausible, some of which actually say it is because of the use of fluorocarbons; others saying it is destruction of gases in the atmosphere; and others saying it is part of the solar cycle. Really, to come up with a better idea of what is happening, we need more research.

It is truly hard to differentiate between them.

Dr. **Rowland**. On the solar cycle suggestion, I would like to comment. Senator Gore earlier mentioned the International Geophysical Year. At the time not only was a measurement for carbon dioxide started at Mauna Loa in Hawaii, but there were a series of stations to measure ozone started all over the world. One of these was at a place called Halley Bay on the coast of Antarctica. We have measurements since 1957 of the amount of ozone over that particular station, and the average amount through the late 1950's and the 1960's was 300 to 330 Dobson units.

Bob Watson's movie showed 225 Dobson units starting in 1979. So the Antarctic ozone concentrations had already fallen a substantial amount relative to the 1950's and 1960's by the time that movie even started. The earlier loss of ozone was something that was being noticed in the late 1970's, but only by the British at Halley Bay, at their station they had been operating since the International Geophysical Year in 1957.

Senator **Baucus**. Is there any significant difference in the scientific community as to what is happening here and what the potential adverse consequences might be? You all seem to be fairly much in agreement, the three of you, with variations of differences, but very small variations. Is there any significant disagreement in the scientific community as to the causes of this phenomenon or its potential effects in the next 60 to 75 years?

Dr. **Watson**. I refer to the two phenomena as Antarctic ozone and global warming. I think on the global warming issue, there is probably not much difference in our reasoning. With global warming, it is a question of magnitude and timing. On the question of Antarctic ozone, I think there is a spectrum of views. I think we are all extremely concerned about seeing such a large, unexpected, unprecedented change in anything in our environment.

I don't believe we know what the processes are that are causing those changes. That is where there is a spectrum of opinions. I know we are all extremely concerned and we would all like to know what the reason is for the change. Until we understand the reason for the change, we can't say for certain the implications of that change.

Senator **Baucus**. I see my time is up. One very quick question. Where should the bulk of the research be; what area? It is one thing to say research; something else to say what kind of research. Where is the research needed to better document or better identify what we should be doing for public policy?

Dr. **Rowland**. My first reaction is that for some of the aspects, we don't need more research; what we need is regulatory action. One can want to control chlorofluorocarbons either because of the contribution to the greenhouse effect or because of its contribution to the depletion of ozone. These are the only trace gases which are relatively easy to control because we are producing almost all of it ourselves. So I could imagine putting on worldwide controls for the emissions of chlorofluorocarbons.

From my point of view, we don't need to have any more information to know that we ought to be doing at least that much. In terms of monitoring what is going on with the other gases, then we have to have a very widespread program to keep track of all of these changes.

Senator **Baucus**. What country is the greatest offender?

Dr. **Rowland**. There is no greatest offender. The United States is right up there near the top, but we have had controls on chlorofluorocarbons in their use as aerosol propellants, and that has reduced somewhat our fraction of the world use. But West Germany and Japan and Italy and France and Great Britain are all important contributors to fluorocarbon emissions, and, of course, all of the developed world are important contributors to carbon dioxide emissions.

Senator **Baucus**. Thank you very much. My time is up.

Senator **Chafee**. Gentlemen, I am going to ask you a question. Suppose each of you were king and you had what you might call unlimited authority. What would you do about this problem? I will start with King Watson.

Dr. **Watson**. Thanks, once again.

I think with respect to the ozone issue, we have to look at all the gases that contribute to a potential change in ozone: the fluorocarbons, methane, CO_2, and nitrous oxide. I don't personally like the approach of banning the specific use of substances like was done in the United States in 1978. While I recognize that it certainly helps to ban the specific use of one substance, therefore reducing the amount, in this case, of fluorocarbons into the atmosphere.

A much more logical approach, if you want to ban or regulate the fluorocarbons, is to put an emissions cap on the total amount of gas that goes into the atmosphere. It doesn't matter what the use is. It matters that it is getting into the atmosphere. I think a protocol at this time that limits the amount of fluorocarbons that get into the atmosphere is an extremely wise approach. I would advise pushing very hard for a protocol. The area of disagreement is exactly where we should put that limit.

Would you have a complete ban of fluorocarbons or limit them at today's production levels? For the time being, I would limit it to something like today's production or thereabouts and still have an active research policy that would probably, within the next few years, provide more information. However, we should not focus just on the fluorocarbons, but we should consider all the gases discussed today. All of these gases affect both climate and the ozone issue.

Therefore, I think we have to look at all the gases, including methane, nitrous oxide, and CO_2. These are very hard policy options. I think if you isolate or focus on one gas; that is, fluorocarbons, which are relatively easy to regulate, that would be the wrong approach. We would be solving a very small part of the problem. We will be back here soon saying, "We covered the fluorocarbons; now what do we do about CO_2 and nitrous oxide?"

We have to look at our combustion policies which affect atmospheric levels of nitrous oxide and CO_2. In addition, we have to try to understand what produces methane; this requires we do need more research. We don't understand why methane is changing, and it is changing at 1 percent per year. If we don't understand why it is changing, then we certainly can't control it.

Senator CHAFEE. Dr.Rowland?

Dr. ROWLAND. If I were king, the first thing I would do is consult with the queen, who is sitting behind me and who has a very good view on what the sensible things to do in such cases are. Then what I would do, I think—I brought with me a magazine called "Bild der Wissenschaften," and you didn't specify that I was king of the world, but I gathered only king of the United States.

Senator CHAFEE. No; king of the world.

We don't travel second class here.

Dr. ROWLAND. The atmosphere is a world problem. I am looking at this magazine, which is the German equivalent to "Scientific American", and on the front is a picture of the atmosphere and the ozone molecules and underneath it says, in German, "Humanity is destroying the protective shield of the earth, the ozone drama."

I think what I would do is start in on the chlorofluorocarbons. I would replace all of the perhalocarbons on a short-term basis, with anything such as fluorocarbon 22, which is a much less hazardous compound to the ozone. Then I would switch as soon as possible to those such as fluorocarbon 134 that have no hazard at all.

There are problems in controlling the other trace gases. We are very much involved in trying to measure methane around the world, and its emission is a process which is largely influenced by man, because methane comes from swamps and from rice paddies and from cattle. Things like rice paddies and cattle are influenced by man, but it is going to be very hard to do anything about something like that.

I think there is a possibility that we can control, in some respects, the emissions of carbon dioxide, but as has been mentioned, its release is primarily from burning fossil fuel and would require reconstructing powerplants. It is hard enough to construct them not to give off sulfur dioxide without taking off the carbon dioxide, as well.

I think we would want to be looking at those releases very closely, and anyplace that you can see that you can cut down on emissions, then I think we should be doing it.

Senator CHAFEE. Dr. Hansen.

Dr. HANSEN. I am sorry if I sound like a befuddled scientist rather than a king, but I would like to understand the problem better before I order any dramatic actions. It is a very complicated global system, and we are just beginning to be able to model it. So I think that what I would like to see most of all, as I mentioned earlier, is global observations during the next decade, observations of the atmosphere, of the oceans, of the land surface, which allow us to see what is happening better and allow us to develop and test the models to represent what is happening.

Finally, I would like to point out that in my personal opinion, the supply of two key ingredients needs to be increased in order that we could use such observational data to quantify the greenhouse effect and to develop adequate models and understanding. One of these key ingredients that we need is an influx of young scientists with appropriate training. We must begin training students now if we are to have scientists available in the next decade when the need for the information, I believe, is going to increase and the pressure to help define appropriate actions is going to be a lot greater.

The second key ingredient, in my opinion, is more research funding for this kind of work. We are spending more and more time pursuing smaller and smaller research grants. I think that has an effect on our productivity in this work. So if I were king, I would ask for some research funding.

Senator **Chafee**. Let me ask you each again, it seems to me that Dr. Watson said that dealing with the chlorofluorocarbons is but a small part of the problem. Dr. Hansen says, Let's have some more research, yet Dr. Rowland says, Certainly, let's tackle the CFC's right away, because that is something we can do.

It seems to me that although we are not going to achieve perfection, we are probably not going to be able to substantially decrease the carbon dioxide emissions. But why not go after the CFC's? There is something we can do and do something more exciting, Dr. Watson, than merely keep them at the same level or, it seems to me, that I looked at Dr. Hansen's charts. Option B was a little discouraging. Maybe it is B, where we took some rather bold steps that was somewhat more encouraging.

Dr. Watson, my question to you is: Why not proceed at least against the villain that we do know exists, even though it may not be the total villain?

Dr. **Watson**. I think we know all of the gases are villains, sir; none of them are perfect, but are all villains in different amounts. Some of the uses of CFC's are extremely important such as refrigeration and air-conditioning. Some of the other uses are rather frivolous, such as aerosol propellants, and foam blowing and Big Mac containers.

You may put a social judgment on what uses you want to ban it from. However, Dr. Rowland may well be right that there are easy substitutes for fluorocarbons in refrigeration. If he is right, we can move fairly aggressively against this industry. If he is wrong, I think we would have to look much more closely.

I think we have to have a social judgment here of the utility of these gases for social uses. I would not like to see a society without refrigeration. We also have to be somewhat careful that if we turn from one use of a chemical and replace it with a chemical, that the chemical doesn't have adverse environmental effects that we don't know about.

The opportunities Dr. Rowland mentioned are quite interesting. I don't suggest they have any detrimental effects. What we do in regulations is we ban one substance, we start to use another substance, and the alternative is just as detrimental to the society, but we don't find out about it for a few more years. I think we should move with some caution, and some of the use of fluorocarbons are enforceable.

Senator CHAFEE. Any other questions, gentlemen?

Senator STAFFORD. Mr. Chairman, yes; one or two occurred to me. Just for my understanding for a somewhat befuddled Senator here, am I correct that plants basically absorb CO_2 as part of their metabolism and exude oxygen?

Dr. ROWLAND. Yes.

Senator STAFFORD. So that should we cut down on CO_2 too much, we would thereby put the plant life at risk. Am I correct on that? That isn't likely to happen, but I assume it could.

Dr. ROWLAND. Without carbon dioxide, plant life would be in great difficulty. But none of the conceivable control systems are going to reduce the amount of carbon dioxide below what we have now.

Senator STAFFORD. Thank you. I assumed that was so. I had one comment. If I instead of you were king, since I am chairman of the Senate's Education Committee, I would try to funnel more money in the direction of producing the scientists, Dr. Hansen, that I am sure we need or for whose need you express a view.

Finally, I can't resist the temptation, Dr. Watson, of asking an elementary question.

That is, after listening to you all morning, are you Australian, New Zealand, or British?

Dr. WATSON. You are roughly 180 degrees off. I am English.

Senator STAFFORD. Thank you very much. Thank you.

Senator CHAFEE. Senator Baucus?

Senator BAUCUS. If it is true that we will experience inevitable carbon dioxide increases, maybe even nitrous oxide increases, and more fluorocarbon increases, and if it is also true that inevitably, unless there is some dramatic change in some of the ozone depletion, are there any beneficial effects from any of those developments?

One can argue that perhaps additional CO_2 means healthier plants. I don't know if that is true or not. I am just curious. Are there any beneficial effects?

Dr. WATSON. With relationship to the ozone issue, I don't see any beneficial effects to changing either the column or the vertical distribution. I can only think of adverse effects. There are no beneficial ones. In the climate issue, maybe. Changes in the distribution of precipitation may be beneficial for some countries and very detrimental for other countries.

It is clearcut with respect to ozone changes; that is, any changes cannot be an improvement for society, however, the climate issue may be a bit more complex.

Senator BAUCUS. Any other reactions?

Dr. ROWLAND. If rain falls on the Sahara and not on Western Europe, it may be good for the people that live in the Sahara and bad for the people in Western Europe, so that there are some mixed aspects of that. I do think that when one looks into the future at global warming and says, "Well, will 3C be good for us?" I think we ought to go beyond that and say, "What happens if we continue it?"

I don't think there is anybody around that argues that 30 °C would be good for us. So the question of whether the greenhouse effect might be good for us for 10, 15, or 30 years and then turn bad in the middle of the next century is one for which we don't know the answer. But I think in the long term, the steady increase in temperature leads to the extinction of biological life, but that is a few centuries away.

Senator **Baucus**. One other final question. For international cooperation, what is your prescription? What is the best way for us to achieve international cooperation here? Obviously, if one country takes a major significant step and the others don't, we are not getting anywhere.

Dr. **Watson**. I think on the side of research, some of you may have already heard about Global Change, or the International Geosphere-Biosphere Program which will be coordinated in the United States by the National Academy of Sciences and be implemented internationally through the International Council for Scientist Unions. I think that this particular program which is currently being developed and will be implemented during the next few years is extremely important. It will focus on environmental issues such as global warming and ozone depletion.

In addition, we should look at how the atmosphere, the ocean, and terrestrial ecosystems all interact. That type of program from a scientific perspective is a very good one. I am personally encouraged to see the international science community working well, at the moment, at both the national and international level. I think it can only be better in the future.

As far as international regulations is concerned, if one is going to go in that direction, I believe it should proceed through the auspices of UNEP which has already put the convention together. UNEP is the international mechanism, it seems to me.

Senator **Chafee**. Thank you, gentlemen, very much for attending. The next panel is Mr. Andrew Maguire, vice president for policy affairs, World Resources Institute; Dr. George Woodwell, director, the Woods Hole Research Center, Woods Hole, MA; Dr. Warl Wunsch, professor of physical oceanography, Massachusetts Institute of Technology, Cambridge, MA; Dr. Steven Leatherman, associate professor, Department of Geography, University of Maryland.

If anybody wants to leave or shift chairs, now is the time to do it. Do I understand that Dr. Woodwell and Dr. Wunsch have a time problem? Dr. Woodwell, what is your problem?

Dr. **Woodwell**. An airplane at 12 o'clock.

Senator **Chafee**. An airplane at 12 o'clock. You have got more than a problem; you have got a disaster.

Let's start with you first, and your plane leaves at 12 o'clock?

Dr. **Woodwell**. There is another at 1 o'clock. I have to make a plane from Kennedy Airport at 3 o'clock, and I can probably do it if I leave at 1 o'clock.

Senator **Chafee**. You just tell us what time. You have to catch the 12 o'clock plane?

Dr. **Woodwell**. Yes.

Senator **Chafee**. Yes. All right, go ahead. Why don't you proceed first, then?

STATEMENT OF DR. GEORGE M. WOODWELL, DIRECTOR, WOODS HOLE RESEARCH CENTER

Dr. **Woodwell**. I was delighted to hear the discussion this morning.

Senator **Chafee**. You must have been getting more and more nervous throughout.

Dr. **Woodwell**. I was particularly pleased to hear the degree of sophistication in the Senate and the large amount of work that has clearly been done already in mastering this very complicated topic. I am going to make the topic even more complicated. The topic, as you did not hear from the previous panel, is also a biological problem.

There is, in the atmosphere, about 700 billion metric tons of carbon. There is another at least 2,000 billion metric tons of carbon stored in the forests and the in soils globally. Presumably, that carbon is available for mobilization to some degree, perhaps 20, maybe even 50 percent.

In the normal circumstance, over long periods of time, there is an approximate equivalency between the processes that fix carbon out of the atmosphere, referred to as photosynthesis, and the processes that break down that fixed carbon, the carbon compounds of plants and soil, into carbon dioxide, heat, and water. That series of processes is respiration. The products of respiration, I emphasize, are carbon dioxide, heat, and water, the same products as those of fire. The products of photosynthesis are fixed carbon compounds. In the normal course, those two processes, photosynthesis and respiration are roughly in balance over the Earth.

We think that is true, but there is no absolute proof of it. A change in the climate has the potential for changing the balance between photosynthesis and respiration over very large areas. The experience of ecologists who think about such topics leads them to believe that the factor that affects that balance most is temperature.

You observed in the data that Dr. Hansen offered a few minutes ago that there will be a large warming in the middle to high latitudes. The extent of that warming is really, no matter how large it is, small in proportion to what is required to produce a large biological effect.

In those latitudes there resides at least 25 percent of the total inventory of carbon held in the biota and the soils. A change in the temperature of 10 °C has the common effect of changing the rate of biotic processes by a factor of 2 or more. The rate of respiration is particularly sensitive to such a change.

So a 1 degree change might increase the rate of the process, respiration, by 10–20 percent. We are talking about changes over the course of decades, a few decades, a very short time as measured by the time that is required to change the distribution of vegetation, the time required to build a forest. We are talking about changes on the order of degrees, 10 degrees or so, in those high latitudes.

For a warming of that scale, there is no process that will affect photosynthesis equivalently. There is no change in the insolation, the incoming solar energy received by the plants; no change in the length of days.

There may be a change in the season, a longer summer season, for example. But whether that will affect the total photosynthesis is an open question. Here again, we are on the edge of what scientists know. The best guess at the moment is that the warming will increase respiration considerably more than it will affect photosynthesis. The effect will be the release of additional carbon dioxide, methane, and probably carbon monoxide from the vegetation and soils.

So here is a positive feedback system: a warming makes the problem with carbon dioxide and other trace gasses worse.

Second, it is possible, but far from proven, that part of the increase in methane already being observed is due to the increase in the temperature of the Earth as soils respire more rapidly. Soils, of course, respire partly anaerobically and produce methane, among other products.

There is still a further factor that is related to this set of considerations. It is easy to change the climate enough to destroy a forest. Consider the Eastern Deciduous Forest at its juncture with the Boreal Forest in middle to high latitudes. Over the short period of years to decades, we expect the climate to change substantially across that border, changing the climate where the southern limit of the Boreal Forest is now to one that will support the Deciduous Forest. Plants of the Boreal Zone will die.

To regenerate a forest in that area where the Boreal Forest trees have died will require years, decades, perhaps a century or two. If the zone moves 200 miles north or 100 miles north or just a mile or two north, it takes a long time for the heavy seeds of deciduous trees, such as acorns, to be moved such a distance.

This means that there will be a wave of mortality in forests not matched by any migration of the species that make up the forest, far more than trees, in that time. This constitutes a wave of what I think of as biotic impoverishment, because we lose not simply the forest in that area, but we lose the combinations of genes that make it possible for trees and other species to exist in that place.

You can think about an island, say, one of the Galapagos Islands, which has vegetation characteristic of a moist climate, and suddenly, in a matter of decades, the climate becomes arid and the individuals of species that require a moist climate die. The species are eradicated. There is no source of seed remaining to replace them if the climate changes to one that might support them.

So the best estimate that one can make here is that these climatic changes, occurring at these rates which are very high rates in the history of the Earth, will lead to what I think of as biotic impoverishment over large areas and will be particularly serious over the middle to high latitudes. Second, the changes will contribute additional trace gases to the atmosphere, especially carbon dioxide.

Such changes are unacceptable. They can be avoided, perhaps, but avoided only by bold action now. It is clear that the major source of carbon dioxide is combustion of fossil fuels; the secondary source, but a large one, is deforestation; another source currently is probably the warming of the soil globally.

These steps are appropriate now: First, an energy policy for the nation that moves us away from dependence on fossil fuels.

Second, policies in management of forests in the tropics, in particular, because it is there that deforestation is progressing most rapidly.

Third, there is no question as to the need for research. The world's research program at the moment on this subject certainly does not exceed $30 million annually. The U.S. research program is run by the Department of Energy. Its current budget is about $12 million, a trifling amount of money in a world in which this series of changes is even a remote possibility.

The research should embrace not only the meteorology you have heard about, but also basic research in ecology and the subjects that I have dealt with. There is a vanishingly small amount of that research on these topics underway at the moment.

Senator **Chafee**. Dr. Woodwell, if we are going to get a couple of questions in and you are going to catch that plane, why don't you wind it up fairly soon?

Dr. **Woodwell**. Right. The fourth point I would make is that one of the most important pieces of data now not being accumulated is the rate of change in the area of forests. That can be measured using satellite imagery and other supplementary techniques. Along with that datum would come additional information about the character of forests. Forests are so large in this calculus that it is madness not to have data flowing in regularly, monitored on a year-by-year basis, telling us what is happening to forests around the world. We have the capacity for taking those data at low costs, probably a total cost for the first survey of less than $5 million.

Appropriate action now has the possibility of delaying the time when the climatic change will be on us. It will be a series of stringent steps, but it is, in my view as a biologist and citizen, necessary that we get about that business. I appreciate your interest.

Senator **Chafee**. Thank you, Dr. Woodwell. You have given us a rather doomsday picture here, which I won't argue with. It seems to me that is the issue of a call to action immediately. I listened carefully to what you said. The final part is increased research, but it seems to me you have outlined what has to be done. I am not arguing against increased research, but you don't think we can wait for increased research before taking these steps which you outlined, do you?

Dr. **Woodwell**. I think we know enough about this topic, and we have known enough about it for at least a decade to move toward alleviating the problem.

Senator **Chafee**. Senator Stafford.

Senator **Stafford**. Thank you, Mr. Chairman. I don't think I really have a question. I have been very much impressed with what you have said, Dr. Woodwell.

A personal note, though; I did want to say, seeing that you are from Woods Hole, that my first assignment in the Navy in World War II was at the Woods Hole section base. I happened to be in midshipman school, which was on Eel Pond when the war started, and my assignment there lasted 6 months. It was the only part of the war I enjoyed.

Dr. **Woodwell**. Come back.

Senator **Chafee**. Senator Baucus.

Senator **Baucus**. I want to thank you, too. You have a plane to catch. That was a very articulate and very provocative statement, and we thank you very much.

Senator **Chafee**. You better buzz along. I wouldn't loiter.

Thank you very much, Dr. Woodwell, for coming; acorns appreciate.

Dr. **Woodwell**. Thank you; sorry to be so rushed.

Senator **Chafee**. Dr. Maguire, we welcome you here.

STATEMENT OF DR. ANDREW MAGUIRE, VICE PRESIDENT, WORLD RESOURCES INSTITUTE

Dr. **Maguire**. As you are hearing at this very important session this morning, Mr. Chairman, we have reached a dramatic moment. Apart from nuances, the international scientific community has reached a consensus: Mankind's activities are changing the atmosphere in ways that could profoundly affect the habitability of the Earth. The magnitude of the risks is unprecedented. The question is: What do we do?

We now know our human species will determine its destiny through our choice of energy sources, our controls on emissions of nitrous oxide and other atmospheric pollutants, our policies toward the use of chlorofluorocarbons, and I stress this, the speed with which we act intelligently in these scientifically complex, interrelated areas.

The scientific findings now include these especially striking specific conclusions: First, the doubling of greenhouse gases will occur twice as rapidly as we previously thought, as early as the 2030's.

Second, the entire climate system—precipitation, winds, storm patterns, soil, and temperature—will be affected on a scale unprecedented in human experience. We must go back 100,000 years to find global temperatures comparable to those now expected in the next century, and greenhouse gases may rise to a level not experienced on Earth for as many as 100 million years.

Third, the greenhouse warming which is anticipated may be associated with a sea level rise of 4.5 feet or more. Especially the eastern seaboard and gulf coasts would be vastly changed from what we know them to be today.

Fourth, the net result of all this could be devastating for U.S. agriculture. A recent analysis of likely changes in seasonal soil moisture concluded that there is strong evidence for summer reduction of soil wetness over large areas of the Great Plains as well as Western Europe.

Fifth, there has been a dramatic retreat in European glaciers since 1850 and a warming in the Southern Hemisphere since 1951 which has produced the 3 hottest years on record in 1980, 1981, and 1983.

Sixth, it is known that even small changes in stratospheric ozone leads to thousands of additional skin cancers, including fatal melanomas. As you can see from the data on the Antarctic, we have here an example of rapid, dramatic change of the sort that scientists recognize could once again shake the judgments and projections made even most recently, accelerating climate change more rapidly than even the current speeded-up consensus suggests.

As you and others, Mr. Chairman, suggested today, some problems are almost too overwhelming to comprehend in terms relevant to our daily lives. Nuclear war is the classic example. Because it is so frightening, there is a tendency to avoid talking about it. Likewise, the profound changes implied by climate and ozone change can lead us to look away or seek excuses for delay.

But let's consider for a moment how sensitive our lives are to relatively minor changes in temperature and climate.

First, the Sahelian droughts in Africa, the most devastating of any climate-related catastrophes of our time are associated with only modest climate variations.

Second, weather events have been wreaking havoc in many parts of the United States this year. But while "extreme" by our normal standards, they are nothing compared to a global warming. In Utah, extensive flooding has caused the Great Salt Lake to rise alarmingly, threatening an interstate highway, an airport, and forcing hundreds of families to evacuate. The Great Lakes have risen about 2 feet and may displace entire communities, inflicting damage of more than $1 billion by current estimates. Meanwhile, large parts of the Southeast United States experienced record droughts leading to extensive forest fires and stunted crops.

Third, we experience terrible human and economic losses whenever summer temperatures are higher than normal. The unusually hot summer of 1980, for example, is estimated to have had a role in more than 1,000 deaths and to have cost billions of dollars in agricultural losses and increased energy use.

Fourth, the El Ninos we have heard about, unusually warm waters off the Pacific coast of Latin America, have been associated with catastrophic reduction in anchovy harvests, severe droughts in some regions, and heavy flooding in others.

With all due respect to one of the previous witnesses, Dr. Hansen, I would submit that one challenge of greenhouse warming and ozone modification is that we must act before all the dimensions of the problem are fully known, or we will risk irreversible catastrophic changes. While research continues, Government action or inaction will have a great effect on the rate of growth in emissions of trace gases. This hearing is momentous, because it is the first to ask not only what is the problem, but what can we do?

If we curtail emissions of CFC's and growth in CO_2-producing energy remains moderate, we can limit the extent of the effects and delay the most serious changes for decades. But the timing of action will also have a considerable impact on how precipitous the actions must ultimately be and, therefore, how difficult and costly.

Let me stress that even relatively modest short-term actions may make an important long-term difference. The World Resources Institute proposes that active collaboration between scientists and policymakers begin immediately and contain these preliminary elements:

First, each affected government agency should include explicit consideration of climate and ozone change through a climate assessment program relevant to its jurisdiction.

Second, since we cannot solve these problems by ourselves, the President should raise the issue at appropriate opportunities, including the next United States-U.S.S.R. summit, as you, Mr. Chairman, have proposed. Similar efforts should be made to involve the People's Republic of China, because they project dramatic increases in coal use in that country, which already uses about the same amount of coal as we do, and as the Soviet Union does.

At the highest levels we should encourage other governments to join with us in reducing CFC emissions. An OECD conference of ministers should be a priority this year, I believe, Mr. Chairman.

Third, we should adopt incentives and controls that increase our options and buy time for solutions, such as further reductions on the use of CFC's; promotion of energy conservation through more efficient technologies; accelerated development of renewable energy sources; and curtailing local deforestation, as proposed in a recent joint publication by the Word Resources Institute, the World Bank and the United Nations Development Program.

Mr. Chairman, if I may be responsive to some of your earlier questions and suggest some specific steps for each of the gases that we have been discussing:

For CO_2 increase energy efficiency through additional regulations like those we now have on automobiles but fail to provide for appliances. Second, reduce deforestation. Third, shift the fuel mix from more to less carbon-intensive fossil fuels. For example, natural gas produces less CO_2 than coal, and it might lead us to a reassessment of the Power and Industrial Fuel Use Act, which, of course, a decade ago we passed to preserve natural gas.

With respect to CFC's, encourage innovation and substitution for CFC's. Second, develop better methods of recycling and recapturing them when they are used; and third, reduce emissions in the disposal and manufacturing processes. All of these things can be accomplished today.

With respect to nitrous oxides, reduce coal use generally, of course, and shift to less nitrogen-intensive coal to reduce N_2O.

With respect to methane, first, encourage strong controls on auto emissions of carbon monoxide to reduce methane formation and second, provide penalties unnecessary for methane emissions and leaks from, for example, natural gas pipelines.

Finally, Mr. Chairman, we should begin now to examine the technical aspects and to fashion a political consensus for more aggressive policies such as a carbon tax on fossil fuels, since such approaches may soon prove necessary.

Thank you very much, Mr. Chairman.

Senator **Chafee**. Thank you, Mr. Maguire.

Senator **Chafee**. Dr. Wunsch, we welcome you.

Mr. **Wunsch**. I would like to speak to some of the roles that the oceans as a whole play in this question as to how our climate is going to change.

Senator **Chafee**. Could you pull those mikes a little bit closer, Doctor? Thank you.

STATEMENT OF DR. CARL WUNSCH, PROFESSOR OF PHYSICAL OCEANOGRAPHY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. **Wunsch**. It has been well known for many years that the oceans play a rather central role in the question of how our climate is going to change under the greenhouse warming. What has not been quite so clear is the great uncertainty that the ocean introduces into the question of the rates at which these changes are going to take place.

In my own view, you have a different problem societally if you have serious changes taking place over 20 years than if they take place over 100 years. To a very great extent, that uncertainty has been ignored in the kind of modeling efforts of Dr. Hansen and others that you heard about previously.

I am not belittling those efforts, because I think they have done the most sensible thing. But what has tended to be forgotten in these decisions is that the ocean itself is not going to remain fixed under this greenhouse warming, and the consequences of the change in the ocean are not quite so obvious as perhaps the models would lead you to believe.

Now, the ocean plays several roles in our climate system, and in particular, insofar as it is affected by the trace gas problem. On the one hand, as the ocean itself warms, which it inevitably will, sea level will rise. Sea level will rise for two different reasons. It will rise because ice will melt; it will also rise because the ocean itself will get warmer. Warmer water occupies larger volume and both these effects will go on.

Second, and more important, perhaps, is that much of the CO_2 which is going into the atmosphere through fossil fuel burning is actually being taken up into the ocean. This has been recognized since almost the beginning. Much of the CO_2 that goes into the ocean is taken by the ocean and placed deep in the water and effectively removed from the greenhouse effect, except on extremely long time scales. The models that you have heard discussed presume that the rate at which CO_2 is taken up by the ocean will continue into the indefinite future.

The ocean is also a sink for heat; the ocean is cold. To the extent that the warming of the atmosphere of the surface waters of the ocean takes that heat and then is carried by the ocean's circulation deep into the ocean, one also delays some of the warming that we will see here where we live, in the atmosphere. Although there is little argument about how large that ultimate warming will be, there is a good deal of uncertainty concerning how fast we are going to see it.

There is another consequence, as well. If I could have a little help in showing this figure, I made a little cartoon at the serious risk of oversimplifying the problem, trying to explain what some of the issues are likely to be. This is a cartoon looking, if you like, from Europe toward North America across the Atlantic Ocean, showing you, in an oversimplified way, how the present day ocean works and is influenced by and influences the atmosphere. Warm water carrying carbon dioxide is carried toward the polar regions today. That water, as it nears the poles, gets cold under the influence of the atmosphere, sinks down near high latitudes, carrying the carbon dioxide with it, and to the extent that it is carbon dioxide laden, injects that carbon dioxide into the deep ocean where it is not again seen by the atmosphere for many years.

The consequence of this pattern, which an oceanographer would call a convective pattern, due to the very dense water sinking at the higher latitudes are several. It makes regions like Europe and the west coast of the United States somewhat warmer than they would otherwise be. We have all been told in school that Europe is warm because the Gulf Stream goes by, but Europe is actually warm because it is so much colder to the north of Europe that the water sinks; as it sinks it sucks warm water up from the south, past Europe, and keeps it warm.

Water that sinks down must ultimately return to the surface. That has a very profound biological consequence. That returning water, which comes back up toward the surface many years later, is rich in nutrients; it is rich in the things that plants and animals live on and things they grow on. If I could have the next slide, it shows one possibility and it emphasizes one possibility of what could happen under the impact of the greenhouse effect.

The wider scientific opinion is very much on the side of what we have already heard, that there is going to be an atmospheric warming and it is very likely to be greater near the poles, and that has several possible consequences for the ocean.

One is that the rate of that sinking is going to be somewhat slower than it is today. Because the water will get less cold, the atmosphere being less cold near the poles during the warming, that will slow down this convective process.

Slowing down the convective process will do a number of things: Less CO_2 will be pumped into the deep ocean. Less nutrient-rich water will ultimately be brought back toward the surface. Whether Europe and the west coast of the United States gets warmer or colder, no one can really say, because the temperature of the water near the surface is a very complicated summation of the effects of this large-scale overturning, which I have tried to indicate here, plus the very local meteorology, which determines the actual temperature of the water which sits offshore.

The models that we have today do not properly account for this process. We cannot actually predict what the ocean is going to do. Is it going to do this? It may well be. It is very possible, perhaps even likely, that that change will be seen.

The oceanographic community, in trying to respond to the needs of the modelers, is very much in the position of a meteorologist, who is forced to predict the weather for next weekend, let us say, when he is not permitted to know what today's weather is.

The message that I would like to leave with you is the following: The ocean does introduce an enormous uncertainty into the rate at which the warming, and the rate at which sea level will rise, is actually going to occur.

We cannot make quantitative or useful statements about what the ocean will actually do because we have almost no observations today of the ocean. It is difficult to convince a layman, much less many of my scientific colleagues, that the ocean is almost unobserved today. It is as complicated as the atmosphere, but we don't live in it; we live on its edges. We cannot look through it. We do not have instruments that measure the whole volume of the ocean all at once.

If you think about it, our climatic knowledge of the atmosphere is the result of the needs of the national governments to forecast the weather. Our Government, back in the 1920's, and World War I, did not set out to build a climate-monitoring network. It started to respond to the demands for aviation and agricultural weather forecasts.

The global weather services today provide our climate information. But the ocean is observed by academics like myself with intermittent abilities to maintain observations for short times.

So in closing, I would tell you that our problem about the ocean, apart from the potentially profound importance of its effects on this climate problem, is that we have no idea what is going on out there today, much less any ability to tell you, with any degree of confidence, what is going to happen.

Thank you.

Senator **Chafee**. Thank you very much, Dr. Wunsch.

Now Dr. Leatherman. We welcome you from the University of Maryland. Dr. Leatherman.

STATEMENT OF DR. STEVEN LEATHERMAN, ASSOCIATE PROFESSOR, DEPARTMENT OF GEOGRAPHY, UNIVERSITY OF MARYLAND

Dr. **Leatherman**. I thank you, Mr. Chairman. I am happy to be here, and your concern for the coastal edge and the oceans is very much appreciated. I remember your work on coastal resources. I brought you a revised Barrier Island Handbook.

Senator **Chafee**. Good. Thank you

Dr. **Leatherman**. Today, I would like to talk about the greenhouse impact on coastal environments. I brought a few slides with me, if I may use those to start off with.

Senator **Chafee**. Sure.

Dr. **Leatherman**. First, I would like to show the rising trends of sea level rise during the last 100 years or so, particularly for the east coast. We have also seen these types of trends for the gulf coast and, to a lesser extent, the Pacific coast. The general trend has been a rise in sea level, and this has been well documented by many scientists. You see the rise as it occurs in New York, New Jersey, and further south.

The reason this is significant is that the rise in the water level is at least partially due to the greenhouse effect, perhaps about 50 percent of it or so. The rest of the relative sea level rise is due to the subsiding of coastal sediments and some other factors.

The rise in sea level has had a tremendous effect on our beaches. Here we are looking at a beach close to home near Assateague Island, MD. We see a salt marsh peat on the beach. This is evidence for the retreat of this barrier island and in the process, erosion of the beaches. In other areas, we are actually seeing old stumps of forests which were in place, showing up on the shoreline. You see marsh peat and stumps along the beaches after storms along much of the barrier coastline of the United States. Obviously, forests do not grow on beaches.

Clearly, we have had a large amount of beach retreat. This is an ongoing process occurring along approximately 80 percent of the U.S. shoreline. Indeed, it is a global phenomenon. You are now looking at some areas that have been urbanized, some of the barrier islands, such as Ocean City, MD. In this NASA U-2 image, we see that Fenwick Island has been very highly urbanized. The beaches are continuing to erode as the barrier retreats.

We are looking at Ocean City, MD, seeing really narrow beaches and, of course, during winter time, those beaches are almost gone. There is an increased amount of vulnerability as the shore erodes, which can eventually result in loses of these structures. In fact, the National Hurricane Center has some data which shows, that on a statistical basis the amount of storm damage has increased tremendously along our beaches over time. In fact, it has been said that perhaps this is the second largest national liability, second only to Social Security.

This illustration shows that we do have a long-term trend of shoreline erosion; Again, using Ocean City, MD, as an example. Essentially, what this slide illustrates is that indeed, we are looking at long-term trends of erosion over at least the last 100 years.

This is true for most areas that we have mapped. We are seeing beaches which are quite narrow and becoming narrower with time.

The key is that the projections indicate an accelerating sea level rise in the future. The National Academy of Sciences has made projections in two reports—1983 and 1985. The Environmental Protection Agency, among others, has also made projections of sea-level rise. Essentially, these projections range from about 50 centimeters to over 200 centimeters, with the National Academy of Sciences' 1983 Revelle report showing about 70 centimeters of rise by the year 2100. That is really quite a change in sea levels.

One of the questions that emerges is: Why are the beaches retreating? This diagram shows that as the water level goes up by a very small amount, this means the upper part of the beach profile must erode and the sediment is moved offshore to balance that amount of material. This is beach erosion. This is what we have been seeing for at least the last 100 years along most of the east and gulf coasts of the United States, and also the Pacific coast to a lesser extent.

There have been some case studies completely, most recently for Ocean City, MD. These tables indicate the amount of beach erosion. Based on various estimates, and considering particular timeframes, we can project the amount of beach erosion.

I should point out that already many of our recreational beaches are critically narrow. Therefore, this means that we are going to see shorelines retreat under some buildings in the future. I show you an example at 44th Street in Ocean City. Right now, we are at time 2 on this diagram. Time 3 is the year 2000 based on the current trend, and time 4 is if we had even a low-level sea-level rise. You can see that buildings are going to be sitting out in the water. That is, high-rise buildings are going to be sitting, if they withstand the erosion, perched out on the beaches like this.

Other problems of sea-level rise involve the marshes. What will happen to our tidal wetlands? You might argue that the beaches are eroding and urbanized coastal areas are going to suffer future damage. Perhaps the marshes can just shift landward with the sea-level rise. The problem here is that marshes form a flat plain. As sea level rises, new marshes will be formed, but you will only have a percentage of the marshes in the future compared to the present. This is because the wide plain is backed against an upward sloping mainland—not a flat plain. There will be quite a bit of marsh loss with sea-level rise.

The other problem is that in many areas, the uplands behind the marshes are urbanized; this is particularly true for New England. Where protective walls—bulkheads—have been built, between the marshes and the urbanized construction, the marshes are going to be completely squeezed out with sea-level rise. There is no place for them to migrate.

Now we are looking at some marshes closer to home. This slide shows Blackwater National Wildlife Refuge in Cambridge, MD on the Eastern Shore of the Chesapeake Bay. We have air photos of this area extending back to 1938. You can see in 1938 a healthy marsh with a tidal creek through the middle of it. By 1957, there is less marsh. By 1964, you see more and more open water. By 1972, there is a real disintegration of these marshes. This marsh loss will have an impact on waterbirds at the National Wildlife Refuge.

Most people think about Louisiana when they consider marsh losses. Indeed, Louisiana is losing 4 acres of marsh per day. We are now beginning to see from studies at the University of Maryland that this is not just a problem for Louisiana but, indeed, a problem for Maryland and probably for other areas in the United States as well.

This is a picture of the marshes in Blackwater taken from an aircraft. You can see those interior ponds becoming larger and larger. This area in 1938 was almost solid marsh. Now it is in a stage of disintegration.

We are also seeing marshes disintegrating because of loss of protective barriers. This is a small barrier in the Chesapeake Bay that is nearly eroded through. Of course, the marshes behind at the top, of the picture are going to be impacted. These marshes will also erode and be lost in the near future.

Of course, Louisiana, is the most graphic example of marsh loss. There have been some projections showing the amount of losses in 50 years. The slide shows major land losses based on the present trends, which can be considered a base level trend, not assuming any increases in the rate of sea level.

The solid line on the graph is the amount of marsh that will be lost, and indeed, entire parishes will be under water in 50 years. As you are probably well aware, 90 percent of these marsh losses in Louisiana are human induced. That is to say, it is due to withdrawal of fluids—oil, water, and gases—so that the land is actually sinking. The land surface in many of these deltaic areas is dropping about 1 centimeter per year. The land surface is dropping rapidly, and the marshes cannot keep pace. They cannot keep their head out of the water; they become waterlogged and die.

This slide shows the rates of land loss that are being projected in the future. My point is that Louisiana might be a very good analog for what can be expected to occur elsewhere for our tidal wetlands. I have a few recommendations.

Senator **Chafee**. Let's hear them.

Dr. **Leatherman**. The recommendations I have are as follows. In the places we have looked, there is preponderance of shoreline erosion. We still need more accurate historical shoreline data. Most of

pages tightly bound

our coast has not been accurately mapped. We need the historical data so we can make accurate projections in the future.

Second, we need more research on marshes, basically, the mechanisms of loss and the rates of loss. Indeed, in the Blackwater marshes, you see the interior ponds enlarging at the expense of the salt marshes. Researchers in Louisiana use the wetted tissue analogy—as the water rises, the marshes seem to disintegrate by this water-logging process.

Finally, I think the Federal agencies need to consider sea-level rise effects in their environmental impact statements. Presently, the Corps of Engineers does not consider sea level in their EIS statements. This is also true for the Federal Flood Insurance Program of FEMA and many other agencies.

It is not that these Administrators do not appreciate the problem, it is just that they do not have the mandate, shall we say, the congressional mandate, to include this in their assessments.

Thank you, Senator.

Senator Chafee. Thank you, Dr. Leatherman.

I must say, this panel and the previous panel has brought us some grim news.

I guess it was Dr. Maguire that talked about the problems of nuclear war hanging over the country and the world. I think there is a difference in connection with nuclear war; everybody seems to recognize it and is worried and is doing something about it, whether it is the arms talks in Geneva or whatever it might be.

But here we are dealing with a completely different problem, it seems to me. It is just as ominous for the future of the globe.

But nobody seems to be doing much about it. Although I will say it is encouraging that the United Nations has had these conferences and the Villach meeting that they had last October, last fall.

Let me ask you a question Dr. Maguire.

You made some very specific recommendations on the CFC emissions and the emission of greenhouse gases. How do you think we can best push the other countries into doing something? Let's say we are prepared to take some steps in the United States. How do we get the others to do it?

Dr. Maguire. I think you have to get their attention at the highest levels on CFC's and the ozone issue. There has been a good deal of discussion among the Europeans and ourselves about what needs to be done. It is recognized that it is a serious problem, but the Europeans suggest one approach and we suggest another. There hasn't yet been a protocol to set out the specific actions that will be taken jointly to implement the ozone convention, which has already been signed. That was an important step, but it requires followup.

In this area, we are very close to a point where governments can take the next critical step. It does require leadership.

Senator Chafee. For instance, I understand the Japanese have indicated they are not interested in participating. Is that true?

Dr. Maguire. Well, I am not sure exactly. I gather that has been true, although they have recently been more forthcoming. The question becomes one of how we get it on to our agenda of matters to discuss with the Japanese in a very serious way. We certainly have lots of matters that we discuss with them regularly, and this should be placed on the agenda.

I would think, Mr. Chairman, you are in a very good position to make sure that that kind of initiative comes from our own Government.

Senator **CHAFEE**. Dr. Wunsch, you indicated that we really don't know an awful lot about these great big oceans; we just know something about the fringes. Yet at the university in my State, the University of Rhode Island, they have an oceanographic vessel that takes trips all around trying to ascertain more information about the oceans. Do you think it has got to be on a far bigger scale?

Mr. **WUNSCH**. One of the concerns is that the ocean occupies 70 percent of the Earth's surface, and it is a cliche. It also happens to be true. From the point of view of the scientists, it is a formidable problem in that to understand a fluid system, you have to be able to observe it in all its components all at once. Some of the work that has come out of the past 10 or 20 years of scientific research at the University of Rhode Island in your State and all the other oceanographic institutions has been a recognition that the ocean is a very complicated, turbulent fluid. It has within it something very closely resembling weather. It changes day to day. All its parts interact.

With all due respect, the oceanographic vessels of the University of Rhode Island, like that of all our oceanographic vessels move around the ocean at about 10 miles an hour on a good day. At that rate, it takes you about 30 days to get across the Atlantic once. Once you are in the process of crossing the Atlantic, the ocean has changed from what it was when you set out.

You have looked, in that process, at a very small piece of it. The oceanographic community has started to try to come to grips with this problem of how do you understand a fluid system that is literally two-thirds the size of the Earth's surface and, on average, about 5,000 meters, 15,000 feet deep.

We have learned; we now have a technical revolution on our hands that makes it possible to put into place observational systems capable of beginning the observation of the sea on a global scale in ways that are both necessary in order to try to answer questions that committees like this and others put to us about what the ocean will do, and in ways that scientifically are more sensible, and, I would add, in ways that we could not have done 10 years ago.

We are now, today, in a position to do so, should our Government and other governments set this at a high enough priority.

Senator **CHAFEE**. Thank you.

Dr. Leatherman, I was most interested in what you had to say. I live on a beach, and I have seen that beach seem to shrink and can't understand it because the particular area I am in has not made any significant changes. I thought the beach would come back, because it has been there for thousands of years. You have made a somewhat gloomier prognostication than I had been thinking about.

Dr. **LEATHERMAN**. I must say, I think, Senator, it will be there; it just will not be in the same position. Your Charlestown beaches will roll over into lagoons as part and parcel of the barrier migration process. The problem is, when you put buildings there, they do not roll over very well.

Senator **Chafee**. Including my house.

Dr. **Leatherman**. Exactly.

Senator **Chafee**. I must say, if one took to bed these problems you have all presented, it would make for poor sleeping. Nonetheless, I think it is terribly important that we bring them to light and try and get many of these challenges before, not only our country, but the world.

I am very grateful for each of you coming. I think a long-distance commuter was Dr. Rowland, who came from California. So Doctor, we thank you very much, and all of you, for coming a good distance to participate in these hearings.

Thank you all, and we will go to part 2 tomorrow at 9:30.

[Whereupon, at 12:14 p.m., the subcommittee was recessed to reconvene June 11, 1986 at 9:30 a.m.]

[Statements submitted for the record follow:]

STATEMENT OF THE HONORABLE
ALBERT GORE, JR.
SUBCOMMITTEE ON ENVIRONMENTAL POLLUTION
JUNE 10,1986

Thank you Mr. Chairman.

I am pleased to have this opportunity to testify before the Subcommittee on Environmental Pollution regarding the greenhouse effect. Mr. Chairman, I commend you and the Subcommittee Members for calling this hearing on what I believe to be one of the most serious long-term environmental problems facing the United States and the World.

The greenhouse effect is the result of the buildup of atmospheric carbon dioxide and other trace gases, which is causing a global warming. This could cause glacial ice to melt, leading to increases in the worldwide sea levels, and altering climatic patterns that effect agriculture.

This basic information has not changed since the three hearings that I chaired in the other body on the greenhouse effect. Moreover, the scientific research community is constantly providing us with more data on the impact of the greenhouse effect.

The February 18, 1986 issue of the New York Times contained the article "Significant Rise in Sea Level Now Seems Certain." The story pointed out that many scientists predict a rise in sea level of one foot within the next 30 to 40 years. Even this relatively small increase could push the coast line inland, in some areas, by one hundred feet. This could be felt on the beaches and marshes from Long Island to Florida and throughout the Gulf and Pacific coasts. These fragile lands would shrink in size and decline in number. Louisiana's shore, for example, which now loses 50 square miles annually, would suffer even greater erosion. Fish and shrimp would lose growth habitat, while salt water intrusion would make farmland useless for agricultural purposes.

Such projections are difficult for some to take seriously. One Tennessee newspaper recently ran a cartoon in which a disembodied voice proclaimed: "Oh boy, who wouda thought that someday 'from sea to shining sea' would mean from Denver to Knoxville?"

At the same time, we must do more to learn about the issue. In December 1985, the Department of Energy's Carbon Dioxide Research Division published four volumes of state-of-the-art reports on carbon dioxide and the greenhouse effect. One of the major conclusions was, not surprisingly, that we need to do more research.

For example, of all the carbon dioxide produced by burning fossil fuels and from deforestation, the fate of almost 50 percent of the carbon cannot be accounted for. Clearly, we are nowhere near the point of regulating, but we do need to increase the research and educational efforts both nationally and internationally.

To address this problem, I have introduced Senate Concurrent Resolution 96. The bill calls for an international year of study on the greenhouse effect and would be the beginning of a long-term cooperative analysis by scientists from all over the world.

The legislation would first, coordinate and promote domestic and international research efforts on both the scientific and policy aspects of this problem; second, identify strategies to reduce the increase of carbon dioxide and trace gases; third, study ways to minimize the impact of the greenhouse effect; and fourth, establish long-term research plans.

This legislation would set in motion the coordinated effort needed to provide us the information so that policy makers, including the United States Congress, will be able to take the appropriate actions. Mr. Chairman, I hope that we will be able to work together in the future to help resolve this important problem.

Recently, I wrote President Reagan and urged him to begin an international cooperative effort to address policy options related to the greenhouse effect. On May 28 of this year he replied that the option "to coordinate efforts to deal with this phenomenon" is being reviewed.

Thank you Mr. Chairman. I would be happy to answer any questions.

STATEMENT OF

Dr. Robert T. Watson

Earth Science and Applications Division

Office of Space Science and Applications

National Aeronautics and Space Administration

before the

Subcommittee on Environmental Pollution

Committee on the Environment and Public Works

Senate

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss the current state of knowledge of the physical and chemical processes that control the distribution of ozone in the atmosphere. I have prepared a written statement for the record, which, with your permission I will summarize.

This statement is based primarily on material contained in a comprehensive assessment document titled "Atmospheric Ozone 1985: Assessment of our Understanding of the Processes Controlling its Present Distribution and Change"-World Meteorological Organization Global Ozone Research and Monitoring Project-Report #16 that was coordinated by the National Aeronautics and Space Administration (NASA) and cosponsored by NASA and two other U.S. agencies, the Federal Aviation Administration (FAA) and the National Oceanic and Atmospheric Administration (NOAA); three international agencies, the World Meteorological Organization (WMO), the United Nations Environment Program (UNEP), and the Commission of the European Communities (CEC); and the Bundesministerium fur Forschung und Technologie (BMFT) of the Federal Republic of Germany. Approximately 150 scientists from eleven countries contributed towards this 1500-page assessment report. This comprehensive assessment has been summarized by NASA into a 130-page report titled "Present State of Knowledge of the Upper Atmosphere: Processes that control ozone and other climatically important trace gases"-NASA Reference Publication 1162. This NASA report was submitted to the Congress and to the Environmental Protection Agency (EPA) in January of this year as part of NASA's obligations under the Clean Air Act Amendments of 1977.

For several decades scientists have sought to understand the complex interplay among the chemical, radiative, and dynamical processes that govern the structure of the Earth's atmosphere. During the last decade or so there has been particular interest in studying the processes which control atmospheric ozone since it has been predicted that human activities might cause harmful effects to the environment by modifying the total column amount and vertical distribution of atmospheric ozone. Most of the ozone in the Earth's atmosphere resides in a region of the atmosphere known as the stratosphere. The stratosphere extends from about 8 km at the poles, and 17 km at the equator, to about 50 km above the Earth's surface. Ozone is the only gas in the atmosphere that prevents harmful solar ultraviolet radiation from reaching the surface of the Earth. The total amount of ozone in the atmosphere would, if compressed to the pressure at the Earth's surface, be a layer about one eighth of an inch thick. Figure 1 schematically illustrates the vertical distribution of ozone and temperature. Unlike some other more localized environmental issues, e.g. acid deposition, ozone layer modification is a global phenomenon which affects the well-being of every country in the world. Changes in the total column amount of atmospheric ozone would modify the amount of biologically harmful ultraviolet radiation penetrating to the Earth's surface with potential adverse effects on human health (skin cancer and suppression of the immune response system) and on aquatic and terrestrial ecosystems. Changes in the vertical distribution of atmospheric ozone, along with changes in the atmospheric concentrations of other infrared-active (greenhouse) gases, could contribute to a change in climate on a regional and global scale by modifying the atmospheric temperature structure which could lead to changes in atmospheric circulation and precipitation patterns. The so-called greenhouse gases are gases which can absorb infrared radiation emitted by the Earth's surface, thus reducing the amount of energy emitted to space, resulting in a warming of the Earth's lower atmosphere and surface.

The ozone issue and the greenhouse warming issue are strongly coupled because ozone itself is a greenhouse gas, and because the same gases which are predicted to modify ozone are also predicted to produce a climate warming. These gases include carbon monoxide (CO), carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and several chlorofluorocarbons (CFC's), including chlorofluorocarbons 11 (CFCl3) and 12 (CF2Cl2). CH4, N2O, and the CFC's, respectively, are precursors to the hydrogen, nitrogen, and chlorine oxides which can catalyze the destruction of ozone in the stratosphere by a series of chemical reactions. Concentrations of these gases in the parts per billion range control the abundance of ozone whose concentration is in the parts per million range, e.g. one molecule of a chlorofluorocarbon destroys thousands of molecules of ozone. CO and CO2 can affect ozone indirectly. CO controls the concentration of the hydroxyl radical in the troposphere which itself controls the atmospheric concentrations of some of the gases which can affect stratospheric chemistry. CO2 plays a key role in controlling the temperature structure of the stratosphere which itself is important in controlling the rates at which the hydrogen, nitrogen, and chlorine oxides destroy ozone.

There is now compelling observational evidence that the chemical composition of the atmosphere is changing at a rapid rate on a global scale. The atmospheric concentrations of CO2, CH4, N2O, and CFC's 11 and 12 are currently increasing at rates ranging from 0.2 to 5.0% per year. The concentrations of other gases important in the ozone and global warming issues are also increasing, some at an even faster rate. These changes in atmospheric composition reflect in part the metabolism of the biosphere and in part a broad range of human activities, including agricultural and combustion practices. It should be noted that the only known source of the CFC's is industrial production. They are used for a variety of uses, including aerosol propellants, refrigerants, foam blowing agents, and solvents. At present one of our greatest difficulties in accurately predicting future changes in ozone or global warming is our inability to predict the future evolution of the atmospheric concentrations of these gases. We need to understand the role of the biosphere in regulating the emissions of gases such as CH4, CO2, N2O, and methyl chloride (CH3Cl) to the atmosphere, and we need to know the most probable future industrial release rates of gases such as the CFC's, N2O, CO, and CO2 which depend upon economic, social, and political factors.

One important aspect of the ozone and global warming issues is that the atmospheric lifetimes of gases such as N2O, CFCl3, and CF2Cl2 are known to be very long. Consequently, if there is a change in atmospheric ozone or climate caused by increasing atmospheric concentrations of these gases the full recovery of the system will take several tens to hundreds of years after the emission of these gases into the atmosphere is terminated.

Numerical models are used as a tool to predict to what extent human activities will modify atmospheric ozone and climate. The types of models most commonly used to predict ozone modification are known as one- and two-dimensional photochemical models. One-dimensional models predict changes in the column content and vertical distribution of ozone, but cannot predict variations in ozone modification with latitude, longitude, or season. Major progress has been made over the past few years to develop two-dimensional models which can predict the variation of ozone change as a function of season and latitude. Three-dimensional models which include longitudinal variations are being developed to study the coupling between the chemical, radiative, and dynamical processes which control the distribution of ozone, but these models are not yet ready to perform perturbation calculations.

Because it is now well recognized that the chemical effects of these gases on atmospheric ozone are strongly coupled and should not be considered in isolation, the most realistic calculations of ozone change take into account the impact of simultaneous changes in the atmospheric concentrations of CO2, CH4, N2O, the CFC's, and possibly other gases such as CO, oxides of nitrogen (NOx), and bromine containing substances. The effects of these trace gases on ozone are not simply additive. Increased atmospheric concentrations of CFC's and N2O are predicted to decrease the column content of ozone, whereas, increased atmospheric concentrations of CO2 and CH4 are predicted to increase the column content of ozone. Therefore, it can be seen that the effects of increasing concentrations of CFC's and N2O are to some degree offset by increasing concentrations of CO2 and CH4 as shown in figure 2. This is contrasted to the global warming issue where increased atmospheric concentrations of the same trace gases are all predicted to increase the temperature of the atmosphere in an approximately cumulative manner.

One-dimensional model calculations have been performed to predict how ozone would change with time assuming that the atmospheric concentrations of CO2, CH4, and N2O continue to increase at their current rates of 0.5, 1.0, and 0.2% per year, respectively, for the next 100 years, in conjunction with three different assumptions for the annual growth rates in the emission of CFC's 11 and 12 to the atmosphere, i.e. 0.0, 1.5, and 3.0%. For CFC emission increases of up to 1.5% per year the ozone column changes were calculated to be less than 3% over the next 70 years. With a CFC growth rate of 3.0% per year, the predicted ozone depletion is 10% after 70 years and rapidly increasing (see figure 3). The results of these calculations demonstrate the strong chemical coupling that exists between these gases, and the time scale on which ozone changes are predicted to occur. In essence, when the growth rates of the CFC's are less than the growth rates of CH4 and CO2 only small column ozone changes are predicted because the CFC effects on ozone are temporarily masked. However, when the growth rates of the CFC's exceed those of CH4 and CO2, these gases can no longer buffer the impact of the CFC's and large ozone depletions are predicted.

It should be noted that even when the predicted column ozone changes are small, and hence little change is expected in the amount of ultraviolet radiation reaching the Earth's surface; major changes in the vertical distribution of ozone are still predicted with potential consequences for climate. Figure 4 shows that ozone is predicted to decrease in the middle to upper stratosphere due primarily to the increasing concentrations of CFC's, and to increase in the troposphere due primarily to the increasing concentrations of CH4.

Two-dimensional models predict a significant variation in the ozone column decrease with latitude with the greatest depletions occurring at high latitudes. Depending upon the exact trace-gas scenario used to predict ozone change, the pole to equator ratio of ozone depletion can range from a factor of 2 to 10. Seasonal effects are predicted but are somewhat less pronounced than the latitudinal effects.

One important question that has been debated during the last couple of years is whether the magnitude of the predicted ozone change is a linear or non-linear function of atmospheric chlorine concentration. The issue is still somewhat unresolved although it now appears from most one- and two-dimensional model calculations that ozone change is a linear function of atmospheric chlorine (for atmospheric concentrations of chlorine of 25 parts per billion or less), and that sudden catastrophic global ozone depletions are unlikely with only small changes in the atmospheric concentrations of chlorine. However, this statement assumes that the models accurately represent the real world, yet prudence tells us that we should remember that these models are not perfect and that they cannot explain the observed large changes which are currently occurring in ozone over the Antarctic during springtime. Antarctic ozone is discussed later.

A crucial question is to assess the extent of changes in global ozone that have already taken place, and to compare the changes to what has been predicted by theory. The search for global ozone trends involves looking for small secular changes amidst large natural variations that occur on many time scales. Observations of the total column content and the vertical distribution of ozone have been made for several decades using networks of different measurement techniques. Unfortunately, each of these observational techniques have certain limitations which tends to restrict our confidence in the results. These limitations arise from factors such as the lack of continuity of reliable calibration and the uneven geographic distribution of stations. Statistical analyses of the data is required to identify small trends, amongst high natural variability, using data from relatively few stations.

In general, analyses for the trends in the total global column content of ozone using data from the ground-based Dobson spectrophotometer network show no statistically significant trend since 1970, in agreement with model predictions for the same period when the changes in all of the trace gases are taken into account. It should be noted that the values of total global column ozone in the last three years have exhibited significant variability. Abnormally low values of total column ozone were observed in 1983 following the eruption of El-Chichon and the largest El-Nino event of this century. However, the values of total column ozone recovered in 1984, only to decrease significantly in 1985.

Trend estimates have also been made for the altitude profile of ozone from the network of stations using the Umkehr technique. Deriving an accurate trend for changes in the vertical distribution of ozone is more difficult than for the total column because there are fewer stations and the Umkehr measurements are very sensitive to the presence of aerosols in the atmosphere. Recent volcanic eruptions such as El-Chichon have deposited large quantities of aerosols into the stratosphere and thus the Umkehr data must be corrected. After correcting the derived ozone amounts for the aerosol interference, an estimate of the ozone trend in the middle and upper stratosphere (30 to 40km) gives a 2 to 3% decrease for the period 1970 to 1980. The magnitude of the change is broadly consistent with the predictions of photochemical models which predict that chlorine will have its maximum effect at this altitude.

A recent preliminary analysis of Nimbus 7 satellite Solar Backscatter Ultra-Violet (SBUV) data has indicated that there has been a statistically significant change in both the total column content (a decrease) and the vertical distribution (a decrease in the middle and upper stratosphere) of atmospheric ozone between 1978 and 1984. Further analysis of the data indicates that most of the change has occurred since 1981. It is crucial to evaluate whether the data has been interpreted correctly, and if so, whether the decrease is due to natural causes such as a decrease in solar radiation, the 1982 eruption of El-Chichon, or the 1982 El-Nino event, or whether it is due to human activities such as the use of chlorofluorocarbons. At this time any of these explanations are plausible.

Important new observational evidence on ozone changes has recently been obtained. Data from a single Dobson instrument at Halley Bay (76 S, 27 W) has indicated a considerable decrease (greater than 40%) in the total column content of ozone above the Antarctic during the spring period (late August to early November) since 1957 with most of the decrease occurring since the mid 1970's. Satellite measurements using both the Nimbus 7 Total Ozone Monitoring System (TOMS) and the SBUV instruments have verified this trend over the Antarctic since 1979 and have demonstrated the spatial and temporal variations in this feature. Figure 5 shows the decrease in the monthly mean concentrations of the column amount of ozone over the Antarctic in October observed from 1979 to 1985. Similar ozone changes are not observed over the Arctic. Satellite measurements of the vertical distribution of ozone, nitrogen dioxide, water vapor, and aerosols over the Antarctic during the 1985 spring period have been obtained using the Stratospheric Aerosol and Gas Experiment (SAGE) which was launched in 1984 on the Earth Radiation Budget Satellite (ERBS). This data is now being analyzed and interpreted. It is not yet evident whether the behavior of ozone above the Antarctic is an early warning of future changes in global ozone or whether it will always be confined to the Antarctic because of the special geophysical conditions that exist there. While it has been suggested that these Antarctic ozone decreases are caused by increasing concentrations of chlorine in the stratosphere, no credible mechanism has been demonstrated since the models using present chemical schemes are unable to simulate this effect. Until the processes responsible for the decrease in spring-time Antarctic ozone are understood, it will not be possible to state with any certainty whether it is a precursor of a global trend. At present a number of theories, some chemical, others dynamical, have been advanced to explain the observations. A major field measurement campaign has been planned for this year to study the ozone layer above the Antarctic. This campaign is being cosponsored and coordinated by NASA, the National Science Foundation, the National Oceanic and Atmospheric Administration, and the Chemical Manufacturers Association.

There are now observations of increases in the atmospheric concentrations of the gases predicted to affect ozone, and there are observations indicating that the total column content of ozone has changed significantly on a regional and possibly global scale. In addition, there are indications that the vertical distribution of ozone may also have changed. The question still remains concerning the reliability of the models used to predict ozone change. Given that we cannot directly test the accuracy of a prediction of the future state of the atmosphere, including the distribution of atmospheric ozone, we must test the models by trying to simulate the present atmosphere, including the distribution of atmospheric ozone, or by trying to simulate the evolution of the atmosphere, in particular ozone, over the past few years. This is done by comparing model predictions with atmospheric observations.

We should note that nearly all the key chemical constituents that are predicted to be present in the atmosphere, and that are important in ozone photochemistry, have now been observed. In general, the models predict the distribution of the chemical constituents quite well. However, the measurements are not adequate for critically testing the reliability of the photochemical models. Close examination of the intercomparison of measurements and model simulations of the present atmposphere reveal several disturbing disagreements. One of the major disagreements appears to be that modelled ozone concentrations are typically 30 to 50% lower than measured ozone concentrations in the upper stratosphere where it should be easiest to predict the concentration of ozone, and where chlorine is predicted to have its maximum effect. These types of disagreements limit our confidence in the predictive capability of these models. In the end, however, our predictive capability will be tested by measuring the changes taking place in the atmosphere. This will require careful measurements of critical species to be carried out over long time periods, i.e. decades. NASA, NOAA, and CMA recently cosponsored a workshop to design an "Early Detection of Stratospheric Change" system. This system would be designed primarily to provide the earliest possible detection of changes in the chemical and physical structure of the stratosphere, and the means to understand them. Implementation of such a system is a high priority.

As stated earlier, the observed increases in the atmospheric concentrations of the CFC's, CH4, CO2, and N2O also have direct implications for the Earth's radiative balance through the so-called greenhouse effect. These gases absorb infrared radiation in a part of the spectrum which is otherwise transparent. Presently, and in the near future, changes in the concentrations of trace gases other than CO2 are thought to be contributing to the greenhouse warming of the Earth's surface and lower atmosphere by an amount that is about equal to that due to changes in the concentration of CO2 (figure 6). The cumulative effect of the increase in all trace gases for the period 1850 to 1980 is a predicted equilibrium warming (this neglects the heat capacity of the oceans) in the range 0.7 to 2.0 K, about half of which should have occured to date. Model calculations indicate that the greenhouse warming predicted to occur during the next 50 years should be about twice that which has occurred during the previous 130 years. Thus, problems of ozone change and climate change should be considered together. It is also apparent that what has been previously thought of as the CO2-climate problem should more properly be thought of as the trace gas-chemistry-climate problem.

It is clear that significant progress has been made in our understanding of the physical and chemical processes that control the distribution of ozone. However, we must recognize that significant uncertainties in our knowledge remain, and that these can only be resolved by a vigorous program of research. It is essential that the US goverment and industry continue their strong commitment to studying the upper atmosphere, and that the scientific agencies continue their close collaboration at both the national and international level.

In summary, given what we know about the ozone and trace gas-chemistry-climate problem we should recognize that we are conducting a global scale experiment on the Earth's atmosphere without a full understanding of the consequences.

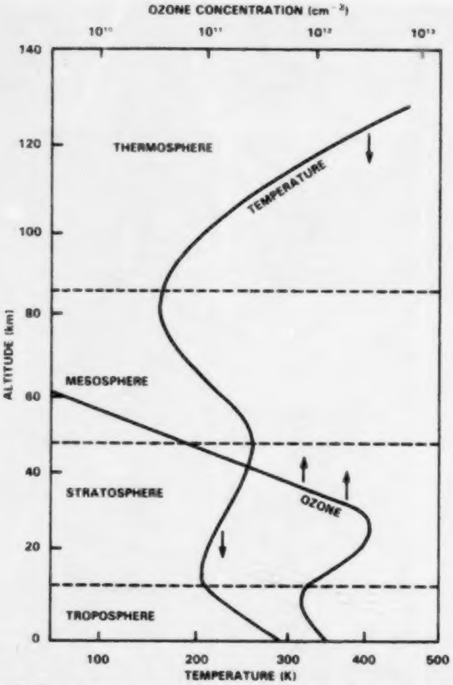


Figure 1. Temperature profile and ozone distribution in the atmosphere.

THESE MODELS HAVE ALSO BEEN USED TO MAKE MULTIPLE GAS SCENARIO PREDICTIONS. THE LAWRENCE LIVERMORE MODEL, FOR EXAMPLE, PREDICTS THE FOLLOWING STEADY STATE PERCENTAGE LOSSES IN COLUMN OZONE FOR THE FOLLOWING ATMOSPHERIC COMPOSITION CHANGES.

PPBV - PARTS PER BILLION BY VOLUME

Figure 2

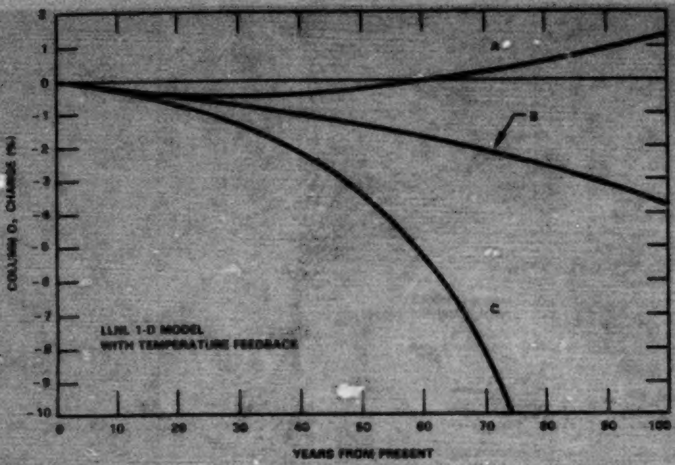


Figure 3. Calculated changes in ozone column with time for time-dependent scenarios: A (CFC flux continues at 1980 level, CH_4 increased 1% per yr, N_2O increases 0.25% per yr, and CO_2 increases according to the DOE scenario); B (CFC emissions begin at 1980 rates and increase at 1.5% per yr, other trace gases change as with A); C (same as B except CFC emissions increase at 3% per yr).

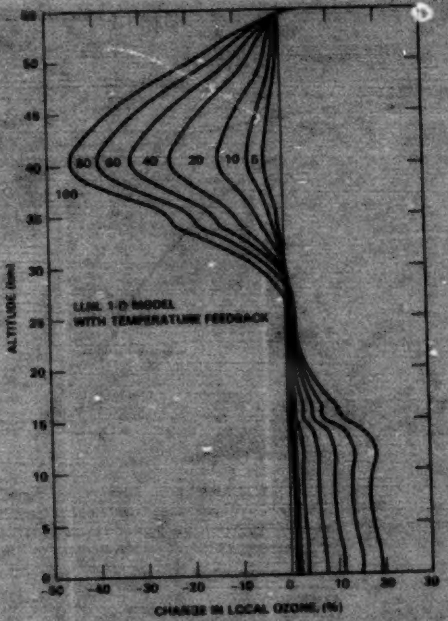
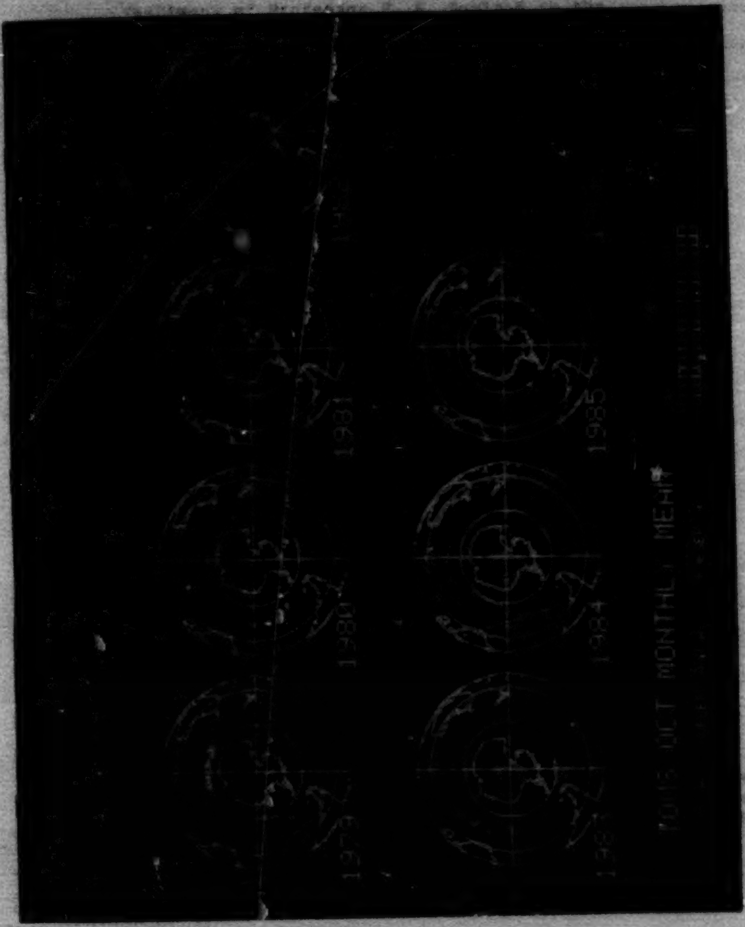


Figure 4. Calculated percentage change in local ozone at selected times (5 to 100 years) for scenario B of Figure 1.


TOMS OCT MONTHLY MEAN
1983
1984
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1981

Figure 5

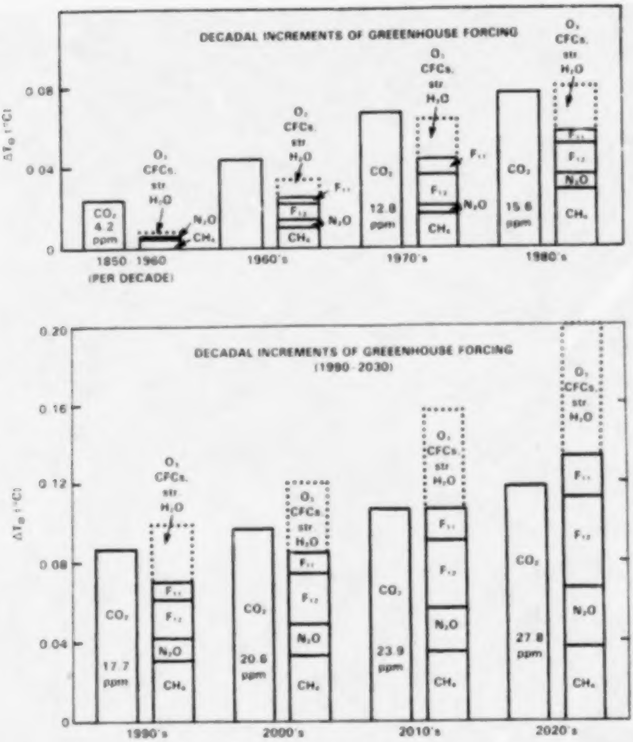

Figure 6. Decadal additions to global mean greenhouse forcing of the climate system. $(\Delta T_s)_0$ is the computed temperature change at equilibrium ($t \rightarrow \infty$) for the estimated decadal increases in trace gas abundances, with no climate feedbacks included.

Testimony of Professor F. S. Rowland to the Subcommittee on Environmental Pollution, June 10, 1986.

In June 1974 Dr. Mario Molina and I published our paper "Stratospheric Sink for Chlorofluoromethanes--Chlorine Atom Catalyzed Destruction of Ozone" in the international scientific journal Nature. This paper carried the first outline of our hypothesis that the chlorofluorocarbon gases would eventually produce serious depletion of stratospheric ozone, and was summarized by the following abstract:

> "Chlorofluoromethanes are being added to the environment in steadily increasing amounts. These compounds are chemically inert and may remain in the atmosphere for 40-150 years, and concentrations can be expected to reach 10-30 times present levels. Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms, and leads to the destruction of stratospheric ozone."

These sentences can, with the benefit of 12 years of intensive study, now serve equally well as a brief summary of the facts of the chlorofluorocarbon-ozone problem.

In early 1974, no measurements had yet been made of any chlorine-containing molecule anywhere in the stratosphere. Now, we have detailed evidence concerning at least ten chlorianated compounds in the stratosphere itself, and of many more throughout the lower atmosphere. The chlorofluoromethanes, CCl_3F (Fluorocarbon-11) and CCl_2F_2 (Fluorocarbon-12), are as they were designed to be, chemically inert. Molina and I reasoned that the usual processes which cleanse the atmosphere of chemical pollutants such as dissolution in raindrops or break-up by visible sunlight would not affect these compounds. The absence of effective removal processes for these chlorofluoromethanes led us to predict two important consequences: The average molecule of each would survive in the atmosphere unchanged for many decades; and removal would occur by destruction in the stratosphere after absorption of ultraviolet radiation.

Both of these predictions have been fully confirmed by actual atmospheric measurements. Both of these compounds have been accumulating everywhere in the lower atmosphere at a very rapid rate and are now found at almost three times the concentrations measured in the early 1970s. This swift build-up is a clear indication that the average atmospheric lifetimes are very long, and current estimates place them as about 70 years for Flurorcarbon-11 and more than 100 years for Fluorocarbon-12. These lifetimes already made clear that any changes in the atmosphere caused by them will still be easily detected not only in the year 2000, but also in 2100 A.D. Although many other possible removal processes -- often described as tropospheric sinks -- have been proposed for these compounds, the facts in the atmosphere have shown these sinks to be totally unimportant.

The concentrations of Fluorocarbons-11 and -12, as well as those of another 10 or 12 halocarbon molecules, have been measured in flasks returned to the laboratory after being carried empty into the stratosphere by ballon and opened by remote control. The mole fractions of these halocarbons decrease with increasing altitude, as expected for molecules susceptible to stratospheric photodissociation, and moreover, do so in the order of altitudes predicted in advance from laboratory measurements of their susceptibility toward destruction by solar ultraviolet radiation. The postulate of stratospheric destruction of these compounds is now simply an accepted fact.

The destruction of chlorofluorocarbons in the stratosphere releases individual chlorine atoms which can then react with ozone to form chlorine oxide. The ozone-depleting ClO_x chain reaction is then completed by the reaction of chlorine oxide with oxygen atoms. Experimental measurements in the stratosphere have amply demonstrated the presence there of both atomic chlorine and of chlorine oxide. With chlorine atoms present, chemical attack on ozone must occur; with chlorine oxide also present, the chain reaction must be complete, and substantial loss of ozone must occur. Since 1974 all of the atmospheric calculations have indicated that this chain should be especially effective in depleting ozone at the altitudes around 40 kilometers (25 miles), with eventual losses there approaching 50%. Two different kinds of measuring devices, one on a satellite and one operated at many different ground stations, have shown a world-wide depletion of ozone at these altitudes over the past 10-15 years.

In summary then, all of the major aspects of the original Rowland-Molina hypothesis have been strongly substantiated by measurements in the stratosphere.

What are the most important additional factors affecting the chlorofluorocarbon-ozone problem beyond those already mentioned? I shall briefly discuss four: The atmosphere as a complex changing mixture of gases; the role of heterogeneous reactions in the atmosphere; the tremendous observed losses of ozone in the Antarctic spring; and "early warning" signals of ozone depletion.

Obviously there is only one Earth and one Earth's atmosphere. All processes affecting this atmosphere occur simultaneously, and the atmosphere registers the complex, accumulated result of all of these changes. In 1974 scientists knew that atmospheric concentrations of carbon dioxide had definitely been increasing since 1957, and very probably had been increasing for about a century before that. In 1986, the atmospheric scientists now definitely know that the concentrations of Fluorocarbons-11 and -12, and several other halocarbons as well, have been increasing very steadily and rapidly; that the pace of carbon dioxide increase has accelerated in the past decade; that methane is increasing as well. Clearly, any other changes in the atmosphere, measured or predicted, can potentially be affected by these other alterations.

For example, an increase in tropospheric ozone is for most purposes not directly connected with the chemical processes which cause chlorine to deplete stratospheric ozone, but is largely a separate problem. The presence of additional ozone in the troposphere is generally unfavorable toward biological species at the Earth's surface, including trees, agricultural crops and man himself. However, if measurements are being made of the total ozone in the atmosphere above a particular location, then an increase in tropospheric ozone can tend to offset a decrease in stratospheric ozone in the observations. If the only ecological ecological concern is the direct penetration of harmful ultraviolet radiation to the Earth's surface -- where it can affect man, for instance -- then a tropospheric increase and a simultaneous stratospheric decrease in ozone do tend to cancel one another because the actual altitude of the ozone is unimportant for such ultraviolet protection. However, if the ecological questions are more broadly framed, then a loss of stratospheric ozone and an increase in surface-level ozone are each an important problem, connected with possible climatic change in the former case and with the direct biological effects of ozone in the latter.

The increasing atmospheric concentrations of other trace gases such as carbon dioxide and methane appear to offer similar trade-offs in the future. The connection between increased concentrations of carbon dioxide and the "greenhouse effect" -- the increased trapping in the atmosphere of outgoing infrared radiation, with condequent warming of the Earth -- has been discussed for about two decades, and in testimony earlier today. The potential contributions of Fluorocarbons-11 and -12 to the greenhouse effect were recognized by V. Ramanathan in 1975, and have been well documented since. Similarly, the increasing atmospheric concentrations of methane also add significantly over the next half century to the rate of global heating which would be expected from carbon dioxide alone.

These same trace gases do interact with the chemistry of ozone depletion of chlorinated compounds. Changes in temperature affect chemical reaction rates, while the chlorine atoms of the CLO_x chain reaction are diverted by methane into the temporary reservoir species, hydrogen chloride -- more methane means more rapid diversion of chlorine in the stratosphere. Calculations have been made with one-dimensional (variation with altitude alone, and not with longitude or latitude) atmospheric models for scenarios with several trace gases increasing simultaneously, and do indeed show little change in the total amount of ozone on a global basis, with substantial losses in the upper stratosphere offset by increases in the lower stratosphere and troposphere. These calculations appear to offer some amelioration over the next few decades in the severity of the ozone-depletion problem from chlorofluoromethanes. This apparently pleasant circumstance is, I believe, illusory for two reasons. First, as has often been pointed out, the real atmosphere is three-dimensional and may not be fully represented by one-dimensional models. Calculations with two-dimensional (altitude, latitude) models also show substantial loss of ozone in the upper stratosphere, but do not indicate as much ozone increase in the lower stratosphere as in the corresponding one-dimensional model calculations. Furthermore, such ozone increases as do occur are largely found in the tropical regions in these two-dimensional calculations. I personally would never describe a loss of upper stratospheric ozone over the United States or western Europe as in any way cancelled or offset by an increase in lower stratospheric ozone over Brazil or India, even if both were to occur.

I say "even if" they were to occur because there is reason to doubt whether any of these one- or two-dimensional atmospheric models is yet including all of the relevant chemical reactions which occur in the stratosphere. The predictions of the one-dimensional models are that the ozone concentrations in the lower stratosphere should even now be increasing with time, coincident with the predicted and observed ozone loses in the upper stratosphere. However, the analysis in the 1986 NASA report specifically notes that the atmospheric observations suggest that the global ozone concentrations have actually been decreasing in the lower stratosphere, in disagreement with this prediction. This discrepancy between model prediction and actual observation strongly suggests some important error in one or the other, and one possible explanation is that some important chemical reactions may have not yet been included in the atmospheric models. This leads to my second important additional factor: Heterogeneous reactions -- chemical reactions which do not take place as the result of collisions between gaseous molecules moving freely, but which are aided by the presence of the irregular surfaces which are found for dust and for ice crystals.

Until about six months ago, the atmospheric model calculations for the stratosphere had included only homogeneous, gas-phase chemical reactions for the understandable reason that no heterogeneous reactions had been demonstrated to be important in the stratosphere. However, one important avenue for the discovery of "missing" atmospheric chemistry is a substantial discrepancy between model calculations and actual observations.

The original Molina-Rowland paper specifically drew attention to the fact that we had not included any heterogeneous reactions in our estimates of future effects. Our reasoning then was directed toward the possibility that inert molecules such as Fluorocarbons-11 and -12 might somehow react more rapidly on the microscopic surfaces of the various particles floating through the air. We thought such decomposition of the chlorofluoromethanes highly unlikely, and this view has been confirmed by their long atmospheric lifetimes. However, some of the chlorinated compounds known to be formed in the atmosphere after the stratospheric decomposition of the chlorofluoromethanes are extremely reactive chemically under laboratory conditions, and we became concerned a few years ago that surface reactions might play an important atmospheric role for such compounds, and especially for the molecule chlorine nitrate. In March 1984 Dr. H. Sato and I began a series of laboratory experiments with this molecule, and eventually concluded that we were simply unable to prevent the heterogeneous reaction of chlorine nitrate with either water or hydrogen chloride on any of the laboratory surfaces which we tested. If chlorine nitrate reacts with water on laboratory surfaces especially chosen for their known inertness, then we must certainly consider the possibility that such reactions can also occur on the surfaces of particles in the atmosphere, including the dust thrown up by volcanoes such as El Chichon in 1982; the sulfuric acid aerosol found throughout the lower stratosphere; and the ice crystals found in the very cold Antarctic winter stratosphere.

No calculations of possible global effects from such heterogeneous reactions of chlorine nitrate have yet been made, although several research groups are already working on the problem. We already know the general direction expected from such modeling from the caluclations in 1984 of Don Wuebbles and Peter Connell of the Lawrence Livermore Laboratory. Two years ago they separately introduced two such reactions of chlorine nitrate, with water in one case and with hydrogen chloride in the other, into the standard one-dimensional model which without them predicted only small changes in total ozone over the next few decades. In each case, the addition of one more chemical reaction to the 160 already included caused a major change, indicating the possibility of very rapid ozone depletion in the next 75 years. Because model simulation of heterogeneous reactions is largely uncharted territory, these earlier calculations do not necessarily have quantitative significance. However, they do show the extreme fragility of the optimistic conclusion "no change in total ozone over the next few decades," when it collapses with the addition of a single, plausible chemical reaction to the atmospheric model.

As you know, wide variations have been recorded over the past decade in atmospheric model predictions of future total ozone depletions. Our initial 1974 estimate of eventual global depletion of ozone was a loss of 7 - 13% one-hundred years or so in the future. Successive official reports from NASA and from the National Academy of Sciences have described the subsequent fluctuations in such predictions, with estimates which have more or less covered the range from 2% to 20%. The range from 2% to 20% was coincidentally the range of uncertainty attached to an estimate of 7% given in the first NAS report in 1976.

Some of these variations have been caused by improvements in the technical details of such modeling calculations, but most have arisen from the inclusion in the model of newly-discovered chemistry, or from improved measurements of the reaction rates for some of the reactions. However, throughout these large oscillations in the calculated total ozone loss, heavy losses have always been predicted for the upper stratosphere. The changes in the results for total ozone loss have been caused by large variations in the lower stratosphere, sometimes indicating decreases there and large global losses in total ozone, and sometimes indicating increases in the lower stratosphere and smaller total ozone loss. The same situation holds true today -- the prediction of future ozone losses are much less certain for the lower stratosphere than for the upper. The lower stratosphere also happens to be the region in which most of the particles are found which might cause heterogeneous reactions.

Clearly, the most striking changes in ozone concentrations which have been observed since regular measurements began 60 years ago are the progressive major losses in the Antarctic during the spring season in the 1980s. These losses were first reported by British scientists using data from ground stations in Antarctica, and have been verified and expanded by data from U.S. satellite instruments and from Japanese high altitude balloons. The Nimbus-7 satellite data for October 1985 show wide areas of the Antarctic continent with extremely low ozone values down to 140 Dobson units [illegible] 330 recorded by the British during the 1950s and 1960s. This loss of more than 50% in total ozone during the Antarctic spring is not only without precedent anywhere over the globe, but represents a decrease which has happened almost entirely during the 1980s. The initial British publication a year ago pointed out the remarkable correlation between this depletion in Antarctic ozone and the rapid growth in the atmospheric concentrations of the chlorofluoromethanes, and the connection is inescapable. Moreover, when either of the heterogeneous reactions of chlorine nitrate with water or hydrogen chloride is added to the existing two-dimensional atmospheric models, very large depletions of ozone are calculated for the Antarctic spring. A plausible chemical explanation now exists not only for the enormity of the losses, but also for why they occur over Antarctica, in the spring, and in the 1980s.

From my point of view, the first measurement indicating that chlorofluoromethanes were accumulating in the atmosphere in amounts about equal to their total emissions to that date was a very critical observation. The discovery of new permanent components of the atmosphere is a non-trivial alteration, and in retrospect should have been an early warning of possible future atmospheric problems. The Rowland-Molina paper in 1974 was an explicit early warning, and made the nature of the future problem very clear. In the autumn after publication of that paper, I was asked what should one look for in the atmosphere as a proof of the Rowland-Molina theory. My answer was, "Look for chlorine monoxide, the carrier of the chain reaction. If you find chlorine oxide in the stratosphere, then the chain reaction is certainly being depleted." By 1978 Jim Anderson's measurements had demonstrated that chlorine oxide was in the stratosphere, and that was a final "early warning."

Since that time, we haven't been looking for early warnings, but instead have been ignoring them and debating instead over how much ozone depletion we are willing to tolerate as a world society. The atmospheric models used in these debates have always indicated a very large range of uncertainty in the calculated predictions of eventual ozone loss. We could have adopted an attitude of prudent caution for the atmosphere and chosen courses of action based on the possibility that further experiments and study would confirm the largest predicted ozone depletions. These losses have always been judged not to be tolerable, and would have then required government regularory actions placing severe limits on the total organochlorine concentration of the atmosphere, and therefore on the emissions of chlorofluorocarbons. The governments of the world have instead adopted an attitude of prudent caution toward interfering with the chlorofluorocarbon industry, have worried about the possibility that feedbacks and not-yet-discovered science would work to ameliorate or even eliminate the ozone problem, and have avoided severe regulations. With the exception of the bans in North America and Scandinavia on chlorofluorocarbons as propellants in aerosol sprays, no effective regulations exist. As a consequence, the world-wide usage of these compounds is once again expanding because of major increases in other uses, and development of new uses. The exploration of how to stimulate and then satisfy the demand for chlorofluorocarbons in the developing countries is also well under way.

The Antarctic ozone hole has arrived as a profound shock, first because the loses of ozone are massive, and second because it was completely unpredicted. Instead of the unexpected working to ameliorate ozone depletion, it has produced huge losses. We are now in the position of having chosen to tolerate some unspecified amount of ozone depletion, and are now wondering how badly we have miscalculated. We now have a hole in the ozone layer which will last for a century or more, even if the entire world were to stop further emissions of chlorofluorocarbons today -- which is of course impossible.

Will the Antarctic hole deepen? Will it spread, and how soon, to other latitudes in both hemispheres? Can we afford to go for another 5 or 10 years of wait-and-see, of measuring, monitoring and studying?

If our prime concerns are the atmosphere, the ozone layer, and the people it shields, the obvious answer is to discontinue this experiment without waiting for all the answers.

THE GREENHOUSE EFFECT: PROJECTIONS OF GLOBAL CLIMATE CHANGE

STATEMENT OF:

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PRESENTED TO:

United States Senate

Subcommittee on Environmental Pollution

of the

Committee on Environment and Public Works

June 10, 1986

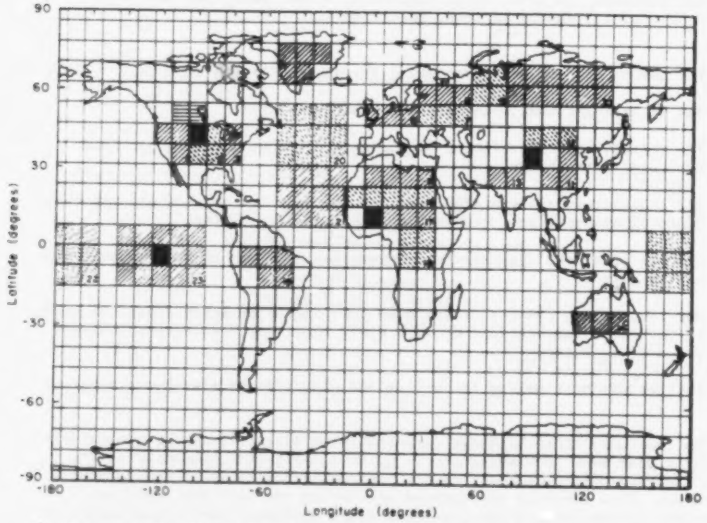
Mr. Chairman, in your letter requesting my testimony you indicated a number of topics I should address, specifically:

1. The nature of our work in modeling greenhouse climate effects.
2. How we test the models to determine their validity.
3. The relative contribution of different greenhouse gases to possible future climate change.
4. The temperature changes predicted for the next few decades and the next century, assuming some reasonable growth in trace gases.
5. How the predicted temperatures compare to past temperatures experienced on the earth.
6. How temperature changes of the magnitude predicted might alter the number of days with temperatures above a given limit for Washington, D.C. and other U. S. cities.
7. Further evidence needed to confirm and quantify the greenhouse theory.

My testimony today is based principally on recent research which will be presented next week in Washington, D. C. at a conference sponsored by the U. S. Environmental Protection Agency and the United Nation's Environmental Programme. This research was carried out during the past few years by scientists at the Goddard Institute for Space Studies. The unique aspect of this work is that it is the first time that a global climate model has been used for simulating the climate effect of the transient growth of atmospheric CO_2 and trace gases. This is an exciting experiment because it allows us to estimate when the greenhouse effect should begin to be evident above the level of natural climate variability. As I will emphasize, a number of caveats must be attached to the climate model results, especially since this represents the first attempt to model the climate of the next few decades. But, as I will also stress, the climate sensitivity of our present model has been extensively compared to that of other models and to available empirical evidence from past climate changes.

GLOBAL CLIMATE MODELING

In principle, global climate models are quite simple. For example, in our model the earth is divided into 'gridboxes' as shown in Fig. 1, and each gridbox is divided vertically into a number of layers, of the order of 10, in the atmosphere. Similarly, the ground or ocean in each gridbox is divided into several vertical layers. Fundamental equations describing the conservation of substances such as mass, energy and momentum are solved numerically for each gridbox by a computer program, which takes account of the transfer of these substances from one box to another and also takes account of physical processes within the boxes which represent sources and sinks of the substances.


90
60
30
0
-30
-60
-90
Latitude (degrees)
-180
-120
-60
0
60
120
180
Longitude (degrees)
20
21
22
23

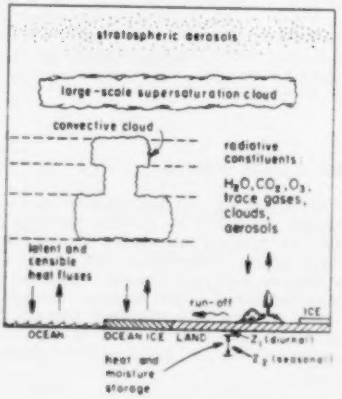
A. Grid spacing for 8° × 10° model. Shadings indicate one choice of regions for special monthly diagnostics. The four black regions are a particular choice of gridboxes for hourly diagnostics.

TABLE 1. Fundamental equations

Conservation of momentum (Newton's second law of motion)	$\frac{d\mathbf{V}}{dt} = -2\mathbf{\Omega} \times \mathbf{V} - \rho^{-1}\nabla p$	
	$+ \mathbf{g} + \mathbf{F}$	(T1)
Conservation of mass (continuity equation)	$\frac{d\rho}{dt} = -\rho\nabla \cdot \mathbf{V} + C - D$	(T2)
Conservation of energy (first law of thermodynamics)	$\frac{dI}{dt} = -p\frac{d\rho^{-1}}{dt} + Q$	(T3)
Ideal gas law (approximate equation of state)	$p = \rho RT$	(T4)

Notation

$\mathbf{V}$	velocity relative to rotating earth
t	time
$\frac{d}{dt}$	total time derivative $\left[= \frac{\partial}{\partial t} + \mathbf{V} \cdot \nabla\right]$
$\mathbf{\Omega}$	planet's angular rotation vector
ρ	atmospheric density
$\mathbf{g}$	apparent gravity [= true gravity $- \mathbf{\Omega} \times (\mathbf{\Omega} \times \mathbf{r})$]
$\mathbf{r}$	position relative to planet's center
$\mathbf{F}$	force per unit mass
C	rate of creation of (gaseous) atmosphere
D	rate of destruction of atmosphere
I	internal energy per unit mass [$= c_v T$]
Q	heating rate per unit mass
R	gas content
c_v	specific heat at constant volume


stratospheric aerosols
large-scale supersaturation cloud
convective cloud
radiative constituents:
H_2O, CO_2, O_3, trace gases, clouds, aerosols
latent and sensible heat fluxes
run-off
ICE
OCEAN
OCEAN ICE
LAND
Z_1 (diurnal)
Z_2 (seasonal)
heat and moisture storage

B. Schematic illustration of model structure at a single gridbox.

Figure 1.

Such global climate models, or GCMs, are able to reproduce the general features of the earth's climate in a gross sense. Changes in climate variables such as temperature, winds and storm tracks and their variations from season to season, from latitude to latitude and from continent to ocean are represented realistically, at least in a qualitative sense. But the models are not sufficiently realistic to accurately portray regional patterns of precipitation, ocean currents, and other processes which are important for determining the practical consequences of climate trends due to greenhouse warming. Recent evidence that the large scale ocean circulation has undergone dramatic changes in the past is of special concern; the representations of oceans in current GCMs are not sufficiently realistic to predict such phenomena.

Improvement of the climate models will depend especially upon better knowledge of physical processes occurring within the climate model gridboxes. These processes are represented by submodels or "parameterizations". For example, Fig. 1b schematically illustrates convective clouds which transport moisture, heat and momentum vertically between model layers. Although there have been major field experiments to study moist convective clouds, substantial work still is needed to provide more realistic submodels for use in GCMs. Another example, which is recently beginning to receive greater attention, concerns the role of vegetation and soil processes in the transfer of moisture, heat and momentum between the earth's surface and the atmosphere. As a final example, it is believed that we must have a better understanding of small scale ocean mixing before we can develop an accurate model of global ocean circulation and currents.

A principal conclusion is that it is likely to require decades of research to improve climate models to the point that they can be used to predict local and regional climate changes with a high degree of confidence. Such improvements will be possible only if appropriate observations of the climate system and climate processes are carried out. In the meantime climate models can provide a useful indication of the possible magnitude of future climate trends, although the results must be accompanied by appropriate explanations and caveats, especially the results at smaller scales.

Finally, I would like to stress one key charactistic of both climate model results and real world climate: natural climate variability. Fig. 2 illustrates the global mean temperature in a 100 year control run of our 3-D GCM. It can be seen that the temperature fluctuates, both from year to year and with decadal trends, even though the amount of atmospheric CO_2 and other climate "forcings" are unchanging. Such variability or "noise" is a natural characteristic of the climate system. Although this phenomenon is captured by the governing fundamental equations in the climate model, individual fluctuations are not predictable. Thus for any climate trend to be detected, it must exceed the level of natural climate variability.

TESTS OF CLIMATE MODELS

A good overall test of the greenhouse effect is provided by examining the climates of several planets, particularly Mars, Earth and Venus, because these planets have a wide range of abundances of atmospheric greenhouse gases. It

pages tightly bound

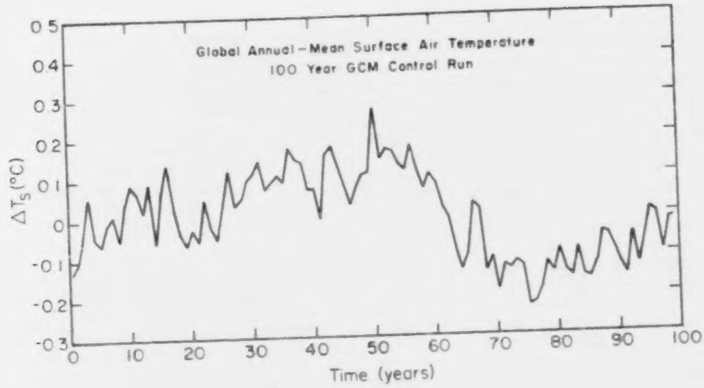


Fig. 2. Global-mean annual-mean surface air temperature in the 100 year control run with the GISS global climate model. Atmospheric CO_2, trace gases and aerosols are unchanging during this run. The ocean mixed layer has observed seasonally and geographically varying depths, and no exchange of heat with the deeper ocean.

is found that these planets are warmer than they would be if they were simply in blackbody equilibrium with the energy absorbed from the sun. The observed greenhouse warmings are a few degrees on Mars, about 35 degrees on Earth and several hundred degrees on Venus. The magnitude of these warmings is in excellent agreement with the greenhouse theory and simple climate models.

Another test, potentially of more direct relevance, is provided by paleoclimate (ancient climate) variations on Earth. This test is only recently beginning to be exploited. The climate of the Earth has fluctuated between ices ages and interglacial warm periods several times during the last few hundred thousand years. It has been realized for more than a decade that small variations in the earth's orbital characteristics about the sun were the 'pacemakers' of the 10,000-100,000 year climate changes, but the mechanism by which global temperature changes were produced remained unknown. Recently it has been discovered that the atmospheric CO_2 abundance fluctuated along with ancient climate, and was thus the probable agent for global temperature chang This identification of past CO_2 warming allows an empirical evaluation of climate sensitivity to a CO_2 change.

In particular, the paleoclimate record indicates that a CO_2 change of 50-100 ppm is associated with a global mean temperature change of 3.5-5°C. The global radiative forcing (ΔT_o) due to this CO_2 change, i.e., the surface temperature change which would occur if there were no climate "feedback" processes, can be accurately computed and is

$$\Delta T_o \sim 0.3\text{-}0.5°C. \qquad (1)$$

Thus the total climate feedback factor f, defined by

$$\Delta T = f\ \Delta T_o, \qquad (2)$$

is f ~ 10 for the recent glacial to interglacial climate changes. Physical processes contributing to f have been analyzed (Hansen et al., in Climate Processes and Climate Sensitivity, American Geophysical Union, 1984), and it has been shown that a substantial part of the total feedback factor is due to the growth and decay of large continental ice sheets, a process which is not significant on the time scale of the next few decades. The feedback factor inferred from the paleoclimate data for processes that are relevant to a change from today's climate toward a slightly warmer climate is f ~ 2-4.

The paleoclimate evidence thus indicates that, if atmospheric CO_2 were doubled from say 300 ppm to 600 ppm and the climate system were allowed to come to a new equilibrium, the earth would warm by

$$\Delta T(2{*}CO_2) \sim (2\text{-}4) * \Delta T_c \sim 2.5\text{-}5°C, \qquad (3)$$

where $\Delta T_o \sim 1.25°C$ is the no-feedback radiative forcing due to doubling atmospheric CO_2.

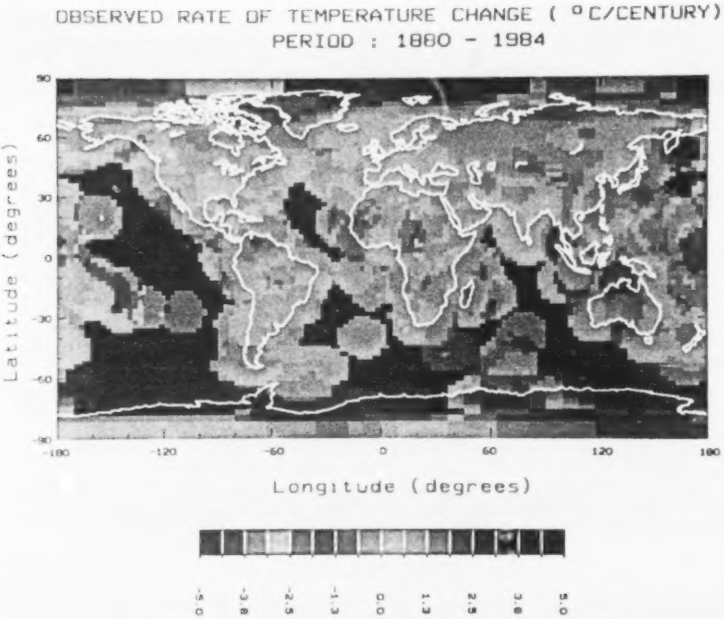
The climate sensitivity inferred from paleoclimate evidence is reasonably consistent with the climate sensitivity estimated by several National Academy of Science studies,

$$\Delta T\ (2{*}CO_2) = 3 \pm 1.5°C, \qquad (4)$$

which was based mainly on intercomparison and analysis of several different climate model studies. Thus there is general agreement about the magnitude of global climate sensitivity, but the uncertainty in its value is at least a factor of 2-3.

Despite all the above evidence, the one truly convincing test of the models must be based on comparison of the models with the observed response of the earth's climate to the present anthropogenically induced growth of atmospheric CO_2 and trace gases. Thus, we illustrate here the temperature changes which have occurred during the past century, a time during which CO_2 has increased from about 280 ppm to 340 ppm and several other trace gases have also increased.

A global map of observed temperature changes is shown in Fig. 3, based on records of meteorological stations. It is apparent that the geographical patterns of temperature change contain a large amount of natural variability, which we should not attempt to associate with a small global forcing, as well as errors in the estimated temperature trends in the regions where there are few stations and short records. The influence of the climate 'noise' and incomplete station coverage is reduced by averaging results over all longitudes. Fig. 4 shows the resulting temperature trends for the period 1880-1984 as a function of latitude.



OBSERVED RATE OF TEMPERATURE CHANGE (°C/CENTURY)
PERIOD : 1880 - 1984

Latitude (degrees)
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
Longitude (degrees)
-5.0
-3.8
-2.5
-1.3
0.0
1.3
2.5
3.8
5.0

Fig. 3. Observed rate of temperature change (°C/century) in the past century, as estimated from meteorological station data. Yellows and reds mark areas of increasing temperature and greens and blues represent decreasing temperature. The black regions have no nearby stations. In some regions the trends are estimated from relatively short records, as short as about 25 years for Antarctica. Results are least reliable in remote regions where only one or a small number of stations contribute to the estimated trend.

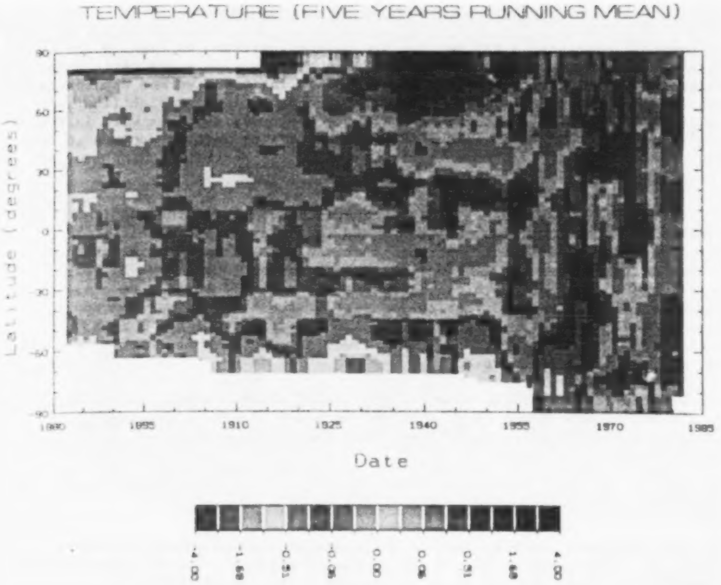


Fig. 4. Observed zonal-mean temperature trends in the past century as estimated from meteorological station data. The zonal-mean refers to the average for all longitudes with available temperature records. A nonlinear color scale is used so that there are comparable areas for the different colors.

Several conclusions follow from the data illustrated in Figs. 3 and 4. The earth has warmed by about 0.6°C (1°F) in the past 100 years, with both hemispheres warming by about that amount. High latitudes warmed substantially more than low latitudes. There is a great amount of local variability, with some regions actually cooling. Although the earth was about as warm in the 1930's and 1940's as it is in the 1980's, the earlier warming appears to have been more concentrated in the high latitudes of the Northern Hemisphere, while the recent warming is more global.

The global warming of 0.6°C in the past century is of the magnitude expected as a result of increasing CO_2 and trace gases. It is difficult to make a more definitive statement than that, in part because the greenhouse forcing is time dependent (most of the growth coming in the past 25 years) and the climate system has a finite response time, probably several decades (Hansen et al., ibid.), so that only a part of the eventual warming due to these added gases has occurred as yet. Also, a warming of 0.6°C is not particularly large compared to climate fluctuations which have occurred in the past millenium, as illustrated below.

We show below that the expected greenhouse climate signal is rising rapidly and should soon rise well above the level of natural variability, providing strong empirical verification of the greenhouse effect.

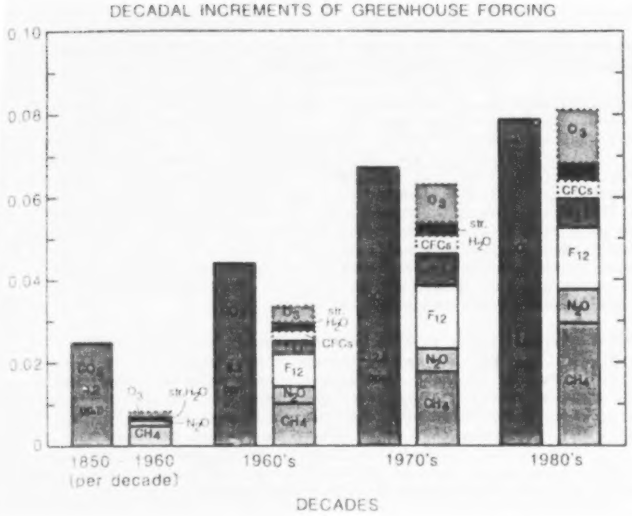
PREDICTED TEMPERATURE CHANGES

The estimated contributions of different greenhouse gases to climate forcing is illustrated in Fig. 5 for different periods. The CO_2 contribution is known accurately, within about 10 percent. The contributions of chlorofluorocarbons $CC\ell_3F$ (F_{11}) and $CC\ell_2F_2$ (F_{12}), compounds which are entirely man-made, are also known accurately. The CH_4 greenhouse contribution is less certain; there is some recent evidence suggesting that the CH_4 contribution in the past few decades may have been flatter than the indicated growth trend. The O_3 and stratospheric H_2O changes, based on a chemical model, are very uncertain and are best described as hypothetical; indeed recent spotty observations of O_3 profiles do not support a positive greenhouse forcing due to changing O_3. But despite uncertainties about the trends of some of the gases, two firm conclusions can be made:

1) In the past few decades the rate of increase of greenhouse forcing of the climate system has increased rapidly; it is now 3-10 times greater than during the previous century, 1850-1960.

2) Non-CO_2 greenhouse gases now add to the greenhouse effect at a rate comparable to that of CO_2.

We have carried out the first GCM simulations of climate trends due to the current changes of atmospheric CO_2 and trace gases. One disadvantage of presenting recent research results is that I can not claim that the results have been confirmed by other climate modeling groups. However, the sensitivity of our global climate model has been compared and found to be similar to that of other climate models at the NSF National Center for Atmospheric Research and the NOAA Geophysical Fluid Dynamics Laboratory. Thus



ig. 5. Decadal additions to global mean greenhouse forcing of the climate ystem. ΔT_0 is the computed temperature change at equilibrium ($t\rightarrow\infty$) for he estimated decadel increases in trace gas abundances, with no climate eedbacks included. Multiply ΔT_0 by the feedback factor f to get the quilibrium surface temperature change including feedback effects. Most of he estimated trace gas increases are based on measurements. However, the $_3$ and stratospheric H_2O trends (dotted bars) are based principally on 1-D odel calculations of Wuebbles et al. (J. Geophys. Res., 88, 1444-1456, 1983).

there is reason to expect that the general conclusions which are discussed below would be similar for the models of these other laboratories.

The global climate model employed for these simulations is our model II documented by Hansen *et al.* (*Mon. Wea. Rev.*, *111*, 609, 1983), which has an equilibrium global mean sensitivity of 4.2°C for doubled CO_2 as documented by Hansen *et al.* (*Climate Processes and Climate Sensitivity*, American Geophysical Union, *1984*). For these transient experiments the ocean mixed layer depth is based on climatology, including geographical and seasonal variations. Heat capacity of the ocean beneath the mixed layer is included by treating heat perturbation as a passive tracer which can diffuse into the deeper ocean; the diffusion coefficient varies geographically as a function of the climatological local stability beneath the mixed layer, according to the empirical relation given by Hansen *et al.* (*ibid.*). Horizontal ocean heat transports are fixed as described by Hansen *et al.* (*ibid.*).

Our GCM simulations begin in 1958, when CO_2 began to be monitored accurately by C. D. Keeling, and extend through the present into the future. We consider two scenarios, A and B, to allow for uncertainties about past trace gas changes and future CO_2 and trace gas changes. Scenario B includes only five greenhouse gases which have been measured reasonably well (CO_2, F_{11}, F_{12}, CH_4, N_2O) and it assumes that their growth rates will decrease rapidly during the next few decades. Scenario A includes an allowance to approximate the greenhouse forcing of the several other hypothesized gases in Fig. 5 and it allows presently estimated growth rates to continue.

Scenario A achieves a radiative forcing equivalent to that for doubled CO_2 about 40 years from now, in the late 2020's. Scenario B achieves this level of forcing in about 2060. The more detailed trace gas scenario of Ramanathan *et al.* (*J. Geophys. Res.*, *90*, 5547, 1985) is close to Scenario A (see Fig. 6). Finally, we note that both scenarios include some additional radiative forcing due to volcanic aerosols, a forcing which tends to cool the surface but generally is moderate in comparison to that from trace gas growth. The aerosol forcing is the same in the two scenarios for the period 1958-1990, with two significant coolings: 1963-65 (Mt. Agung) and 1982-84 (El Chichon). Scenario B assumes that the mean aerosol forcing in the future will be the same as in the period 1958-1990, a period of active volcanism, while Scenario A assumes a negligible future volcanic forcing, as was the case for the period 1910-1960.

Global maps of the temperature changes obtained in the GCM climate experiments are shown in Fig. 7. The detailed geographical patterns of these changes are not to be taken seriously in view of the limitations of current GCM's mentioned above and the gross assumption about ocean heat transports. However, certain semi-quantitative conclusions are expected to be meaningful.

The warming in Scenario A at most midlatitude Northern Hemisphere land areas such as the United States is typically 0.5-1.0°C (1-2°F) for the decade 1990-2000 and 1-2°C (2-4°F) for the decade 2010-2020. Even in the latter decade the warming is much less than the equilibrium response to doubled CO_2, Fig. 7c, which has a warming at about 5°C in the United States. In all of these cases the largest temperature changes are in regions of sea ice and the

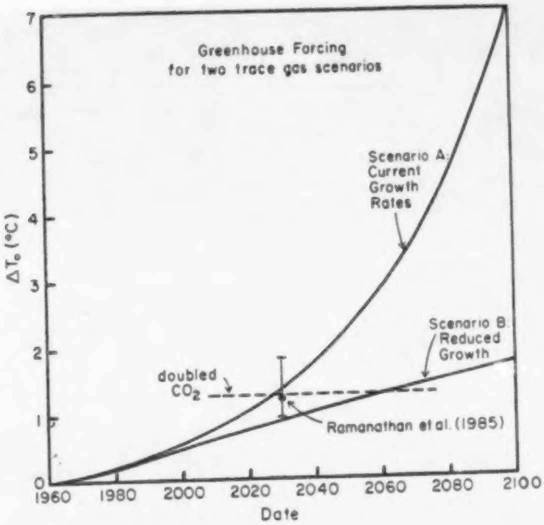
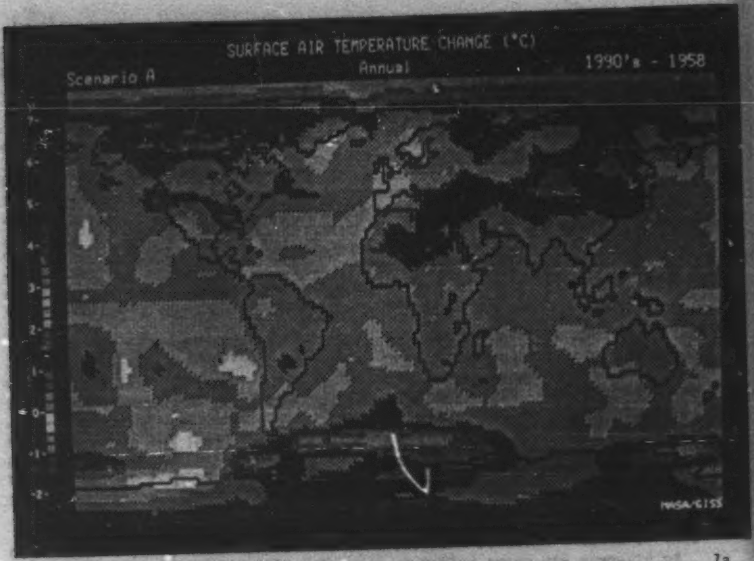


Fig. 6. Greenhouse forcing for two trace gas scenarios. ΔT_o is the equilibrium warming with no climate feedbacks. Scenario B includes only CO_2, CH_4, N_2O, F_{12} and F_{11}, and it assumes that their growth rates will decrease rapidly in the next 25 years. Scenario A includes an allowance for other trace gases hypothesized in Fig. 5 and it allows current growth rates to continue indefinitely.

In Scenario A CO_2 increases as observed by Keeling for the interval 1958-1984 and subsequently with a 1.5 percent growth of the annual increment. $CC\ell_3F$ and $CC\ell_2F_2$ emissions are from reported rates to date and assume 3% yr^{-1} increased emission in the future, with atmospheric lifetimes for the gases of 75 and 150 years, respectively. CH_4 increases from 1.4 ppb in 1958 at a rate of 0.6% yr^{-1} until 1970, 1% yr^{-1} in the 1970's and 1.5% yr^{-1} thereafter. N_2O increases according to the semi-empirical formula of Weiss (1981), the rate being 0.1% yr^{-1} in 1958, 0.2% yr^{-1} in 1980, 0.4% yr^{-1} in 2000 and 0.9% yr^{-1} in 2030. Potential effects of several other trace gases (such as O_3, stratospheric H_2O, and chlorine and fluorine compounds other than F_{11} and F_{12}) are approximated by multiplying the CFC amount by the factor 2.

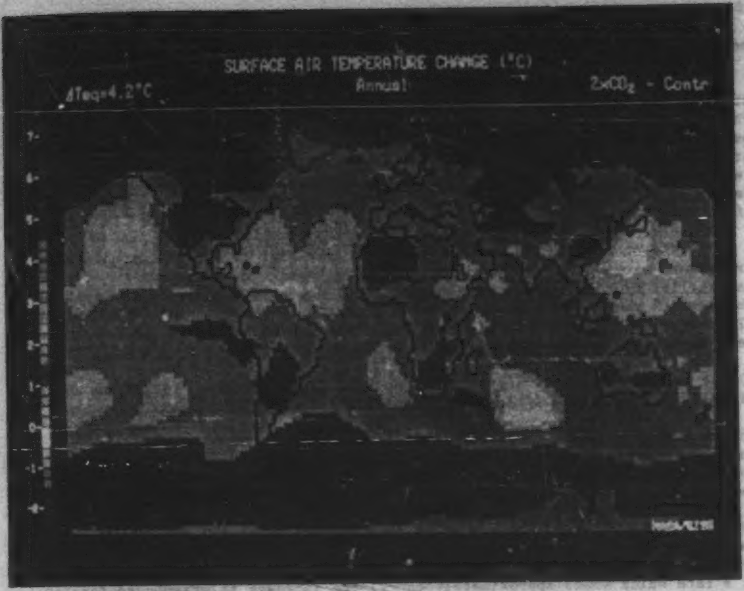
In Scenario B the growth of the annual increment in CO_2 is reduced from 1.5% today to 1% in 1990, 0.5% in 2000 and 0 in 2010. The growth in annual emissions of $CC\ell_3F$ and $CC\ell_2F_2$ is reduced from 3% today to 2% in in 1990, 1% in 2000 and 0 in 2010. The methane annual growth rate decreases from 1.5% today to 1% in 1990 to 0.5% in 2000. N_2O increases are based on Weiss' (1981) formula, but the parameter specifying annual growth in anthropogenic emissions decreases from 3.5% today to 2.5% in 1990, 1.5% in 2000 and 0.5% in 2010. No increases are included for other chlorofluorocarbons, O_3, stratospheric H_2O or any other gases.


SURFACE AIR TEMPERATURE CHANGE (°C)
Annual
Scenario A
1990's - 1958
7
6
5
4
3
2
1
0
-1
-2
NASA/GISS

7a

SURFACE AIR TEMPERATURE CHANGE (°C)
Annual
Scenario A
2010's - 1958
7
6
5
4
3
2
1
0
-1
-2
NASA/GISS

7b


SURFACE AIR TEMPERATURE CHANGE (°C)
Annual
ΔTeq=4.2°C
2×CO2 - Contr
7
6
5
4
3
2
1
0
-1
NASA/GISS

7c

Fig. 7. Annual mean temperature changes computed with the GISS global climate model, which has a sensitivity of about 4°C for doubled CO_2. Figs. 7a and 7b, for the decades 1990-1999 and 2010-2019, respectively, were obtained from the transient experiment with CO_2 and trace gases increasing according to Scenario A; the indicated temperatures are the difference between the transient run and a control run with 1958 atmospheric composition. Fig. 7c is the equilibrium warming in the model for doubled CO_2.

smallest are at low and middle latitude ocean areas.

The global mean temperatures computed by the model are compared to observations in Fig. 8. for the period 1958 to the present. In this period the greenhouse forcing of Scenarios A and B differ by only the order of 10 percent. It is apparent that the observed temperatures and the model results are not inconsistent during this period. But the natural variability of temperature in both the real world and the model are sufficiently large that we can neither confirm nor refute the modeled greenhouse effect on the basis of current temperature trends.

On the other hand, it is also apparent from Fig. 8. that the predicted greenhouse warming for Scenario A rises above the level of natural variability by the 1990's. Indeed, the model predicts a temperature level in the next 15 years which has not existed on earth in the past 100,000 years, as illustrated below. In view of the significance of such conclusions, we stress here the principal caveats which must accompany the result:

1) The model sensitivity is 4.2°C for doubled CO_2. Emergence of the warming signal will be delayed if the true sensitivity is less than that.

2) The projection is based on Scenario A. If Scenario B is more realistic, emergence of the warming signal will be delayed. We estimate that Scenario B would delay the emergence by a few years, but a more quantitative statement requires extention of the Scenario B simulation.

3) Other major climate forcings which tend to counteract the greenhouse warming may occur during the next several years. As one example, satellite measurements indicate that solar irradiance decreased in the period 1980-1984 at a rate which would approximately cancel the increase in greenhouse forcing during the same period. Although decreases in solar irradiance are probably cyclical and must eventually be balanced by comparable increases, it is possible that a decreasing trend could continue for several more years. As a second example, an unusual increase in volcanic activity could conceivably counteract the greenhouse warming for as long as a decade or so: Scenario B contains a substantial amount of volcanic aerosols, similar to the amount in the volcanically active period 1958-1985, but it is possible to have a greater level of volcanic activity.

4) There may be crucial climate mechanisms which are omitted or poorly simulated in current climate models. An example is changes in ocean circulation, such as the formation of deep water (Bennett _et al._, _North Atlantic Deep Water Formation_, NASA CP 2367. 1985). If the rate of deep water formation is reduced, it is possible that the North Atlantic and Europe may cool while most of the world is warming.

COMPARISON TO PAST TEMPERATURES

Global temperature changes are illustrated in Fig. 9 for the past century, millenium and 25,000 years. The global mean temperature has varied by about 0.5°C in the past century and 5°C in the past several hundred

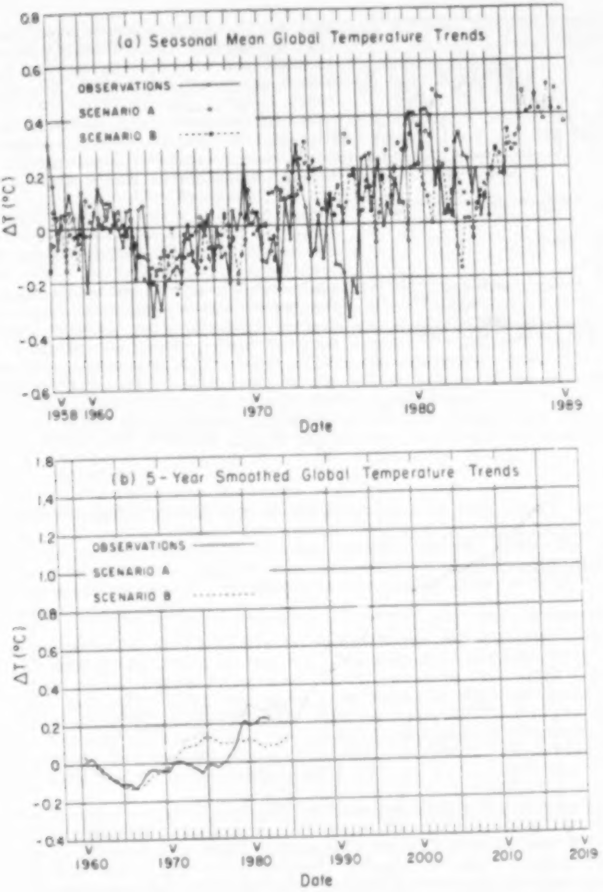


Fig. 8. Global temperature trends from observations (solid line) and from calculations with the GISS global climate model. Part (a) shows the temperature anomalies plotted each season (December-January-February, March-April-May, etc.). Part (b) shows the 5-year smoothed results.

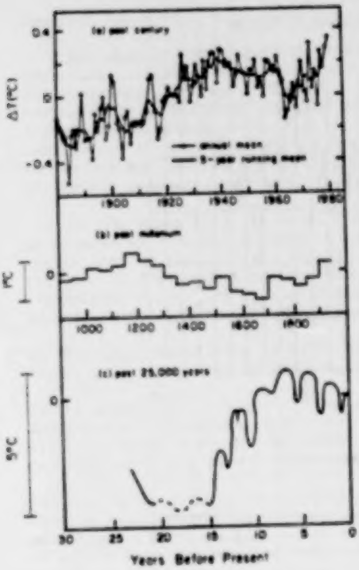


Fig. 9. Global temperature trend for the past century (a), millenium (b) and 25,000 years (c). (a) is based on Hansen et al. (Science, 213, 957, 1981), updated through 1981. (b) is based on temperatures in central England, the tree limit in the White Mountains of California and oxygen isotope measurements in the Greenland ice (W. Dansgaard, private communication), with the temperature scale set by the variations in the last 100 years. (c) is based on changes in tree lines, fluctuations of alpine and continental glaciers and shifts in vegetation patterns recorded in pollen spectra (Understanding Climatic Change, National Academy Press, Washington, D.C., 1975), with the temperature scale set by the 3-4°C cooling obtained in a 3-D climate model (Hansen et al., in Climate Processes and Climate Sensitivity, American Geophysical Union, 1984) with the boundary conditions for 18,000 years ago. Thus the shapes of curves (b) and (c) are based on only Northern Hemisphere data.

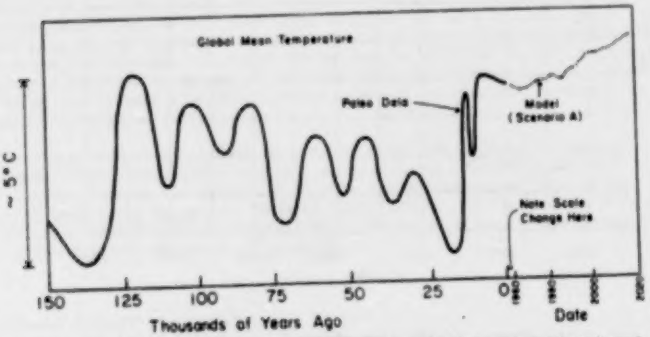


Fig. 10. Global temperature trend for the past 150,000 years (left) and as projected for the next few decades (right) on the basis of the global climate model simulation with Scenario A trace gas trends.

thousand years (Understanding Climatic Change, National Academy Press, Washington, D.C., 1975). During the peak of the current interglacial (Altithermal period 5,000-10,000 years ago) the mean temperature is estimated to have been 0.5-1.0°C warmer than today (Fig. 9.).

We have explicitly compared the temperature changes projected for the next few decades with estimated temperatures for the past 150,000 years in Fig. 10. By the early twenty first century the global temperature should have risen well above any level experienced in past 100,000 years.

TEMPERATURE EXTREMES IN U.S. CITIES

How might temperature changes of the magnitude predicted alter the number of days with temperatures above a given limit for Washington, D.C. and other U.S. cities? This is a particularly difficult question to answer, because the climate models are not designed for local studies. I believe that the best way we can get an estimate to this question at the present time is to compile climatological data for a given city from a long series of daily observations (including maximum and minimum temperatures for each day) and to add to this record the mean (monthly) increase in daily maximum temperature and in daily minimum temperature as predicted by the climate model for the gridbox which includes that city. This procedure tends to minimize the effects of any errors in the model's control run climatology.

This procedure has been carried out for several U.S. cities for the equilibrium change in climate for doubled CO_2, with the work being done principally by Paul Ashcraft as a summer student study. Because of the climate system's finite response time, the results may be most applicable to some time approximately in the middle of the twenty first century, if Scenario A is approximately correct.

The results of this exercise for two U.S. cities, Washington, D.C., and Omaha, Nebraska, are shown in Fig. 11. The number of days per year in which the maximum daily temperature exceeds 100°F increases from about 1 to 12 in Washington and from 3 to 20 in Omaha. The number of days with maximum temperature exceeding 90°F increases from about 35 days to 85 days in both cities. The number of days per year in which the nighttime temperature does not fall below 80°F increases from less than one day in both cities to nine days in Omaha and 19 in Washington, D.C.

There are a number of reasons why these estimates may differ from the real world response. Principal among these are the following: First, the estimates are based on a model with sensitivity 4°C for doubled CO_2; the real world sensitivity is uncertain by about a factor of two. Second, the model assumes that the ocean will continue to operate essentially like it does today; if North Atlantic Deep Water Formation and the Gulf Stream should be substantially modified, for example, that could significantly change the results for a location such as Washington, D.C. Third, there are many reasons why local responses may vary; the indicated changes can only be regarded as plausible for these cities, under the assumption of climate sensitivity equivalent to 4°C for doubled CO_2.

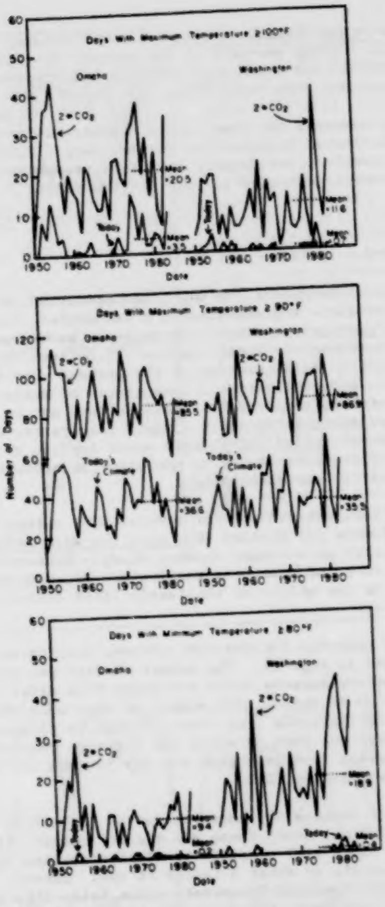


Figure 11. Annual number of days in Omaha, Nebraska and Washington, D.C. with (a) maximum temperature greater than 100°F, (b) maximum temperature greater than 90°F, and (c) minimum temperature greater than 80°F. Today's climate refers to observations for the period 1950–1983. The results for doubled CO_2 are generated by adding the warming obtained in a $2*CO_2$ climate model experiment to the observations for 1950–1983.

Discussion of the practical impacts of greenhouse warming has focused on possible indirect effects such as changes of sea level, storm frequency, and drought. We believe, however, that the temperature changes themselves may significantly affect the climatic environment for the general population.

EVIDENCE NEEDED TO CONFIRM AND QUANTIFY THE GREENHOUSE THEORY

Evidence confirming the essence of the greenhouse theory is already overwhelming from a scientific point of view. However, the greenhouse issue is not likely to receive the full attention it deserves until the global temperature rises above the level of natural climate variability. This will not occur at some sharp point in time, but rather gradually over a period of time. If our model is approximately correct, that time may be soon, within the next decade.

Unfortunately, when that point in time is reached people will begin to ask practical questions and want quantitative answers. We are now totally unprepared to provide that information. Our understanding of the climate system and our climate models must be vastly improved.

The greatest need, in my opinion, is for global observations of the climate system over a period of at least a decade. This will require both monitoring from satellites and in situ studies of climate processes. Prestigious scientific groups, such as the Earth System Sciences Committee appointed by the NASA Advisory Council, have defined the required observations in detail, and there seems little reason to repeat that information here.

TESTIMONY OF G.M. WOODWELL IN HEARINGS BEFORE THE U.S. SENATE SUBCOMMITTEE ON ENVIRONMENTAL POLLUTION, COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

June 10, 1986

I. Introduction

I am George M. Woodwell, Director of The Woods Hole Research Center, Hudson River Foundation for Science and Environmental Research. I am a scientist and a teacher. I have held long term scientific and administrative positions at the Marine Biological Laboratory, at Brookhaven National Laboratory, and the University of Maine and I serve on the boards of various organizations supporting scholarship and conservation. I have worked in research for many years on various studies of the structure, function, development, and impoverishment of plant and animal communities. The work has had a special focus on forests. I am grateful for the opportunity to appear again before this committee, this time to review the biotic implications of a global warming due to changes in the atmosphere now in progress.

The scientific community is rarely unanimous on any issue of wide public importance; its business is, after all, to question, review, examine, test and to argue in search of new insights and new data. But on the issue of climatic change there is surprising unanimity at the moment. If current trends continue, the increase in infra-red absorptive gasses in the atmosphere will lead over the next 3-5 decades to a warming of the earth that will average between 1.5 and 4.5°C. The changes in the tropics will be small; the changes toward the poles in both hemispheres will be much larger. The details of the changes in climates expected have been summarized recently in a report by the National Academy of Sciences (NAS 1983), in hearings in the Congress (1985), and in four volumes published by the Department of Energy (DOE 1985). There can be no question as to the seriousness with which the scientific community views the prospect of an imminent warming caused by human activities (UNEP/WMO/ICSU 1985).

The warming has commonly been expressed as the change in climate anticipated from a doubling of the carbon dioxide (or equivalent as other infra-red absorptive gasses) of the atmosphere above that prior to the surge in deforestation and industrialization that occurred after 1860. The emphasis on a doubling is practical, but misleading. It seems to suggest the establishment of a new equilibrium that will allow equilibration of the vegetation of the earth with the new climates. In fact it simply marks the advent of an indefinite period of instability in climates globally. If current trends continue, the carbon dioxide content of the atmosphere will pass the doubling point sometime before the middle of the next century, when the rate of increase will be substantially higher than it is now. The implications of such changes for the biosphere as a whole are only now becoming the subject of serious thought and research. They are beyond the limits of experimentation or direct observation and outside the consensus that has defined the carbon dioxide problem as worthy of special consideration by governments. I can offer at best judgements based on extensive experience in study of the distribution and metabolism of forests. Subsequent research may modify details of these interpretations appreciably; the general trends described, however, will probably not be altered.

Our interests in the effects of climatic changes are short term, measured in years to decades, not in millennia. The effects are profound. They include effects on the distribution of arable land, the productivity of agriculture, the availability of water in lakes and streams, the productivity of grazing lands and fisheries, and the level of the sea. They also reach to effects on the distribution of the vegetation of the earth, including especially the distribution and viability of forests. It is the effects on forests that are most significant for our purposes and the subject that I wish to call especially to your attention.

The climatic changes projected for the next years will destroy forests over large areas. Two results of this destruction are of special importance. First, the further destruction of forests above current rates from harvesting and from the expansion of agriculture (Houghton et al. 1984, Woodwell et al.1984) will release carbon now stored in forests and tundra, especially in soils, adding carbon dioxide and methane to the atmosphere and speeding the warming. Second, the warming will progress rapidly enough to destroy existing types of vegetation over large sections of the earth more rapidly than species migrate. The effect will be a general impoverishment of the biota at the very time when human demands for biotic resources are reaching new peaks.

II. Effects of a Global Warming on the Metabolism of the Vegetation of the Earth

The atmosphere contains about 700 x 10^{15}g of carbon as carbon dioxide. The terrestrial vegetation and soils, largely the forests, contain at least 2,000 x 10^{15} g, about three times the amount in the atmosphere. This large standing crop of carbon is maintained by a crude balance between photosynthesis, the sum for a unit of landscape of the biotic processes that remove carbon from the atmosphere and form the carbon compounds of plants, and respiration, the sum of those processes that consume the compounds and release carbon dioxide, heat and water.

There is difficulty currently in appraising the effects of the combination of changes associated with a warming of the earth. On the one hand there are those who argue that the increased concentration of carbon dioxide in the atmosphere will increase the rate of photosynthesis globally and result in increased storage of carbon in the biotic reservoirs. On the other hand are those whose analyses suggest that any direct effect of the increase in carbon dioxide in the atmosphere on photosynthesis will be small by comparison with the effects of small changes in climate on respiration. The issue is made more complicated by uncertainty concerning the patterns of changes in climate. A global warming that raises the winter temperatures in the high latitudes will have little effect on metabolism. A warming that affects spring, fall, or summer temperatures may have profound effects. If the climatic changes affect precipitation, there will be still further changes in metabolism, more difficult to predict. There are ample bases for argument among scholars and for questioning virtually any conclusion. Those arguments cannot be allowed, however, to obscure some fundamental facts, which are seen best by examining specific changes in climate and vegetation.

The warming will be global and will be greater in higher latitudes. A global warming of 1.5-4.5°C will involve an average change in temperature in the boreal and sub-arctic zones of as much as 10-15°C. The change in climate will not involve a change in the length of day or a change in the solar energy impingent on the earth's surface. A 10°C increase in temperature can be expected to increase the rate of respiration by a factor of 1.5-3.0, possibly more. There is no obvious mechanism affecting photosynthesis that has the capacity of compensating for such an increase in respiration at these latitudes. The shift in the ratio of photosynthesis to respiration will clearly be in favor of respiration with an immediate further release of carbon from the decay of organic matter in the soils and vegetation of these zones.

The magnitude of the release could be substantial. The total carbon held in these zones in the vegetation and soils is estimated as more than 500 x 10^{15}g, about 25% of the global total. The fraction of this inventory that could be released into the atmosphere is uncertain, but a 10-50% loss is conceivable over the course of the next several decades. Such a release would be in the range of 3-10 x 10^{15}g/year, the same order of magnitude as the current releases from combustion of fossil fuels (about 5 x 10^{15}g/yr) and enough to contribute substantially to the further accumulation of carbon in the atmosphere.

The issue seems especially clear in the higher latitudes where the temperature changes will be greatest and where the accumulations of carbon vulnerable to decay are high. The same process operates at lower latitudes to the extent that temperatures rise. Here, however, there is a greater possibility that increases in the length of the growing season or other factors will stimulate gross photosynthesis on an annual basis and provide some degree of compensation for the increased rates of respiration. The issue is not easily open to short-term research. It is best interpreted on the basis of knowledge of the relationships between climate and the distribution of vegetation, the plant communities including forests that make up the natural vegetation of the earth. Despite the importance of agriculture, it is the forests that carry on the greatest amount of carbon fixation globally and provide the greatest flux of energy in support of life.

III. Effects of a Global Warming on the Vegetation of the Earth

A. Forests at Hazard: Climatic Change and the Distribution of Forests

The warming anticipated over the next years will shift climatic zones abruptly poleward. While there is a tendency for those who inhabit the polar regions to assume that a warming will be a blessing, the changes are clearly a mixed blessing and quite likely to be seen as devastating in many of their aspects.

Consider forests, the most abundant and important vegetation type on land, the principal reservoir of biotic diversity globally, and the major biotic source of energy for support of people and for maintenance of environment. The eastern deciduous forest of North America is transitional on one border along a gradient of increased temperature and aridity to tall grass prairie. On the other border it is transitional to boreal forest. A general warming will change the area of land capable of supporting deciduous forest. Along the warm and dry margin, increased temperature and aridity will cause the extension of the prairie into the forest. At the margin of the deciduous forest with the boreal forest the climate will change from one that supported the boreal forest to one that could support the deciduous forest. Along both these margins trees and other plants, living close to the margin of survival under the earlier climatic regime, will be in a climatic zone for which they are not longer suitable.

The immediate effect is the death of many of the plants of the forest, especially the trees. In the normal course the reestablishment of sufficient climatic stability will lead to the establishment of a new forest, but the transition is a long one measured in human terms, several decades or longer. Meanwhile the organic matter in the trees and soil of the damaged forest decays, releasing its carbon to the atmosphere and contributing further to the atmospheric burden. The net effect is the destruction of forests in the short term and the release of carbon to the atmosphere over that period.

The reestablishment of forests requires the availability of seeds and other propagules that may not migrate as rapidly as climatic conditions change. There has been ample precedent. One classic example is the impoverished shrub vegetation that occurs on the tops of some of the mountains of the southern Appalachians at elevations and under conditions that support forests elsewhere. The cause of the balds, impossible to prove in an absolute sense, appears to be a series of climatic changes that, through a warming, eliminated the spruce-fir forest from certain peaks, where the climate became appropriate for the deciduous forests of the region. A cooling of the climate subsequently eliminated the deciduous forest from the tops of the mountains but, because the coniferous forest had become extinct locally, the vegetation that developed in the deforested zone, even after several decades, possibly centuries, was that of an impoverished shrub bald, not forest. The same pattern of effects can be envisioned for the biota of islands as they are affected by progressive climatic changes. Islands and regions as well as continents contain endemic species that evolved into that place. Such species are especially vulnerable to changes of climate or habitat.

The transition from forest to shrub community, a common stage in the impoverishment of forests globally, whatever the cause, involves not only a change in species, but a reduction in the standing stock of carbon in plants and soil. The reduction contributes carbon to the atmosphere, adding to the problem. The amount, indicated above, is significant in global balance and will contribute further to the climatic change. These factors have not been considered in most recent appraisals of the effects of the increase in infra-red absorptive gasses in the atmosphere. There is no clear biotic mechanism that will in the short term balance this further release of carbon.

B. Plants and Animals at Hazard: Biotic Impoverishment

Forests are the great biotic flywheel that keeps the biosphere functioning as a place suitable for life as we know it. They are also the major reservoir of biotic diversity and contain with their soils an amount of carbon well in excess of the amount currently in the atmosphere. They have the capacity through photosynthesis for fixing atmospheric carbon into the organic matter used in support of life. Their existence requires climatic stability over decades, even centuries, and climatic changes on the scale anticipated over the next years imply the devastation of forests over large areas. While most of us have had experience with attempts to eliminate noxious organisms from gardens, lawns, attics and pantries, and appreciate how difficult that challenge may be, the best approach to eradication is to change the habitat in such a way as to prevent reproduction. And the species most vulnerable to such changes are the large-bodied, long-lived ones. Among plants trees are especially vulnerable and the changes their demise brings are especially important because of the extraordinary influence that trees have on their habitat, establishing the environment for many other organisms, and, to a surprising degree, for humans.

The details of the transitions are as elusive as the details of the effects of nuclear war and, as for war, they will not be available for proof except as a result of the transitions themselves. The effects, although incremental over decades, when summed and recognized for what they are as irreversible impoverishment, will constitute the greatest change that has occurred in the surface of the earth since humans emerged. Worse than war, increments are accumulating now with effects that will occur over years to come.

IV. Reasonable Steps Now

A. The Need for Policy

Human activities are affecting the earth as a whole now and the best estimates at the moment are that the effects will become profound over the next decades. The issues have implications for the human enterprise as fundamental as those of war and peace and economic and domestic security. They require the attention and action of governments.

The immediate causes of the climatic changes anticipated for the next years are the combustion of fossil fuels and the destruction of forests. The climatic changes themselves have the capacity for increasing the release of carbon from biotic sources and aggravating the problem.

Steps toward a solution will require effective policies in development and use of energy that bring, among other advances, control of rates of combustion of fossil fuels and preservation, even the expansion, of existing forested areas globally. They also require the development of international protocols advancing the objectives among other nations of the world, especially those of the tropics. These steps will have many salutary aspects in addition to the immediate objective of alleviating or deflecting global climatic change.

B. The Need for Research

Global environmental questions such as the effects of war, progressive biotic impoverishment and climatic change and its effects are not open to direct experimentation and proof. The undisputed facts in this instance, however, are that the atmospheric composition is being changed rapidly in such a way as to increase the atmosphere's capacity to absorb radiant heat. The cause is the combustion of fossil fuels and deforestation. An additional cause that increases the carbon dioxide, methane and carbon monoxide content of the atmosphere may be the recent warming of the earth, but there is no proof of this point. Actions taken now to correct current trends will become effective years in the future. If those actions are to be guided wisely they require constant and intensive research, including monitoring. Such is the cost of living on the earth under the conditions we have established.

Other factors affect climates globally. They include the energy emitted by the sun, the amount of dust and other particulate matter in the atmosphere, and the cloudiness of the earth's atmosphere. Predictions of the effects of the changes in the gaseous composition of the atmosphere are all based on the assumption that these other factors are also predictable.

Biotic effects are even more complicated, but vitally important. The amount of research in ecology underway at the moment in support of these analyses is negligible, despite the importance of the issues. Much of the research in ecology has been deflected, mistakenly, into studies of the putatively beneficial effects of increased carbon dioxide on the growth of plants (DOE 1985c), neglecting the effects of climatic change on the plant communities that dominate the earth. Despite the importance of forests globally and the ease of measuring changes in the area of forests using existing satellite imagery, there is no concerted effort to use those data to measure even once the changes occurring in the area of forests globally. The information is needed annually as the product of a monitoring program. That is one of the very first steps in improving current estimates of the trends underway, the scale of the problem, the potential effects of a warming, and what might be done to deflect it.

The Department of Energy has been defined as the lead agency within the US Government in directing research on these issues. The program is small. In 1986 the total budget was $12.4 million; in 1987 it is projected as $13.6 million. The total investment in this research in the US, including all the various agencies of gevernment, was estimated as $23.5 million in 1985 and $22.8 million in 1986. The total investment in research on this topic globally probably does not exceed $30 million annually. The US program is severely restricted currently by limitations of money, dominated by perspectives within the Department of Energy, limited in international intitiatives in science or government, and substantially unsupported by other potentially complementary programs in science, technology or policy development. There is clear need now for increased interest within government on this topic, for greater diversity in approaches by the various agencies, for an expansion in the support for research, and for special efforts at stimulating international initiatives both in science and in the development of protocols that may lead to solutions. In this latter realm I call attention to the possibility that the international development agencies, especially the banks, might be encouraged to develop policies, to stimulate research and discussion internationally, and to develop joint programs designed to reduce the hazards of climatic change.

V. Conclusions

1. There is a broad consensus within the segment of the scientific community that works on the carbon dioxide problem that the combined effects of the accumulation of carbon dioxide and other infra-red absorptive gasses in the atmosphere globally will result in an increase in the average temperature of the earth in the range of 1.5 to 4.5°C sometime early in the next century.

2. The climatic changes globally will be severe, but they will be most important in the middle and higher latitudes of both hemispheres where the temperature changes may be in excess of 10°C.

3. The climatic changes are usually considered as the product of a doubling of the carbon dioxide content of the atmosphere above the approximately 270 ppm present in 1860, but the fact is that the change will be from climatic stablility to instability with the warming trend continuing and probably accelerating once it starts.

4. The biotic implications, apart from effects on agriculture, of the climatic changes include:

a. the release of additional carbon dioxide (and other infra-red absorptive gasses) from the destruction of forests and the organic matter of soils into the atmosphere in sufficient quantities to speed the warming;

b. sufficiently rapid changes in climatic zones to cause widespread mortality of plants, especially of trees, leading to waves of extinction of plants and animals. The effects will be most severe in the forested zones of the middle and high latitudes of both hemispheres.

5. The effects of such a warming are sufficiently severe to warrant action to prevent or deflect the continued increase in carbon dioxide in the atmosphere.

6. Prevention will require:

a. reduction in dependence on fossil fuels globally;

b. policies that prevent further deforestation;

c. vigorous and broadly-based programs of research in meteorology and ecology to reduce the uncertainty surrounding knowledge of the causes and effects of climatic change.

7. Appropriate action now has the potential for stabilizing the carbon dioxide content of the atmosphere over the next years and delaying or deflecting the climatic changes.

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STATEMENT OF

ANDREW MAGUIRE
WORLD RESOURCES INSTITUTE

BEFORE THE
SENATE SUBCOMMITTEE
ON ENVIRONMENTAL POLLUTION

HEARING ON THE GREENHOUSE EFFECT
AND OZONE MODIFICATION

JUNE 10, 1986

This Committee is accustomed to dealing with complex and important environmental problems, but perhaps none so complex and important as the related issues of the greenhouse effect and ozone modification. The human condition may depend on the ability of governments to implement policies to reduce the risks before the full dimensions of these problems are understood, for by then it will almost surely be too late.

This hearing is an important first step in what will almost inevitably be an evolutionary process--one hopes a timely one --of identifying effective and acceptable responses to climate change. The Committee's detailed review of existing programs--or, in some cases, lack of programs--by all the relevant agencies may someday be viewed as an historic event. While there has already been an impressive record of international action to protect the ozone layer going back more than a decade, this hearing is important also because it is the first to recognize the linkages between the greenhouse and ozone problems and the need for a coordinated response.

Changing Our Atmosphere: Time to Act

The international scientific community has reached a consensus: mankind's activities are changing the atmosphere in ways that could profoundly affect the habitability of the earth. As the National Aeronautics and Space Administration (NASA) stated in a January 1986 report to Congress, "we are conducting one giant experiment on a global scale by increasing the concentrations of trace gases in the atmosphere without knowing the environmental consequences".

The full dimensions of this experiment are only poorly understood, but the magnitude of the risks is unprecedented. In careful but unmistakable language, scientists are now saying that we can no longer take for granted a biosphere consistent with conditions necessary to sustain humankind. A new detailed Department of Energy (DOE) report on the global carbon cycle concludes with the recognition that "human effects on atmospheric composition and the size and operations of the terrestrial ecosystems represent major excursions that may yet overwhelm the life-support system crafted in nature over billions of years."[1]

Similarly, the recent report from the international Scientific Committee on Problems of the Environment (SCOPE)[2] on climate impact assessment notes that an increase in global temperature of several degrees could trigger an irreversible melting of glaciers, triggered by the most substantial temperature and weather changes in historical time. Will subsequent equilibrium permit the existence of man? The authors' stunning reply: "We do not know."

In the face of implications of such magnitude, we submit that one familiar response to troubling new environmental issues--"let's just do more research for now"--simply won't do. More research is needed, but serious analysis of policy options is long overdue. Evidence of the seriousness of the problems, and of their imposing magnitude, is increasing; it will take considerable time and effort to identify and implement effective policies. However, the level and range of the risks are also very subject to timely policy influence: From what we now know we can say quite literally that our human species will determine its destiny through our choice of energy sources, our controls on emissions of nitrous oxides and other atmospheric pollutants, our policies toward the use of chlorofluorocarbons (CFCs), and the speed with which we act intelligently in these scientifically complex, interrelated areas.

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[1] J. Trabalka et al, "Human Alterations of the Global Carbon Cycle and the Projected Future," in J. Trabalka, ed., Atmospheric Carbon Dioxide and the Global Carbon Cycle (U.S. DOE, Dec. 1985).

[2] R. Kates, J. Ausubel, and M. Berberian, Climate Impact Assessment (SCOPE Report 27, 1985), p.509.

For just these reasons, the scientific community is now encouraging policymakers to put climatic change high on the public agenda. Last October, an international conference of scientists gathered at Villach, Austria under the auspices of the UN Environment Programme (UNEP), the World Meterological Organization (WMO), and the International Council of Scientific Unions (ICSU) to assess the current status of knowledge concerning climate change. They unanimously concluded: "The understanding of the greenhouse question is sufficiently developed that scientists and policy-makers should begin an active collaboration to explore the effectiveness of alternative policies and adjustments."

The World Resources Institute proposes that this much needed "active collaboration" begin immediately and contain these preliminary elements:

- Planning by all agencies should include explicit consideration of climate and ozone change. Virtually every agency of government will be affected and should have a climate assessment program relevant to its jurisdiction.
- The United States should exercise international leadership since we cannot solve these problems by ourselves. The President should raise the issue at appropriate opportunities, including the Summit.
- We should adopt incentives and controls that increase our options and buy time for solutions, such as major reductions on the use of CFCs and regulations that promote energy conservation.
- We should begin to examine the technical aspects and fashion a political consensus for more aggressive policies, such as taxes on fossil fuels, since such approaches may soon prove necessary.

Overall, our adjustment to these problems requires developing new ways of thinking, much as we adapted more generally to the importance of environmental issues in the 1970s.

Scientific Perspective

Both the greenhouse effect and ozone modification are now accepted phenomena; we already have supporting empirical proof. The issue is not "whether" but "when", and with what consequences.

Several major international scientific reports have been published on these issues in the last six months--the Villach Conference, already described; the Department of Energy's four-volume "state-of-the-art" review of carbon dioxide buildup and its effects; and a detailed review of the chemical processes controlling concentrations of ozone and other climatically important trace gases produced by the WMO, NASA, and several other US and foreign agencies. These reviews reveal an impressive international consensus.

Especially striking are these specific conclusions:

1. A greenhouse warming of 3 to 8 degrees F is expected for a doubling of atmospheric CO_2 concentrations above preindustrial levels. This is a global average that will be experienced through a warming larger nearer the poles than at the equator, with a possible sea level rise of 140 centimeters (4.5 feet).

2. Trace gases other than CO_2, including chlorofluorocarbons (CFCs), methane, and nitrous oxides, are now collectively equal to CO_2 in their contribution to the greenhouse effect. These gases are also accumulating above the earth at faster rates. As a result, an effect equivalent to doubling CO_2 could occur at least twice as rapidly as previously thought: as early as the 2030s--less than 50 years.

3. Continued emissions of CFCs at current levels

> would result in ozone depletion (increasing incidence of fatal and non-fatal skin cancers and other serious health hazards, possibly individual suppression of the body's immune system) of 4 to 9 percent for constant CFC emissions and much greater reductions if emissions continue to grow. While growth in emissions of CO_2 and the other greenhouse gases could increase ozone in the lower stratosphere, partially offsetting dangerous depletion in the upper stratosphere, this would only occur in conjunction with a more serious greenhouse problem and potentially harmful changes resulting from shifting amounts of ozone at different altitudes and latitudes.

Our ability to characterize and quantify the effects of this warming and the related changes in atmospheric processes is limited and may remain so for decades. The important point is that the entire climate system--precipitation, winds, storm patterns, soil temperature, etc.--will be affected on a scale unprecedented in human experience. Indeed, one obstacle to predicting the consequences of a climate so much warmer is that one has to go back 100,000 years to find global temperatures comparable to those likely in the next century. Atmospheric concentrations of greenhouse gases may rise to a level not experienced on earth for as much as 100 million years. Neither can these changes be easily reversed; these gases will remain in the atmosphere for decades or even centuries.

Much of what has been predicted, while preliminary, is truly frightening. The most obvious change will be much hotter summers in U.S. cities. According to climatologist Jim Hansen of the Goddard Institute for Space Studies, in a doubled CO_2 world Washington is likely to exceed 100 degrees F. 12 days a year on average, as compared with one now. Days above 90° would more than double, from 36 to 90. In Omaha, temperatures would exceed 100° three weeks a year, rather than three days.

The effects of much warmer weather on human health and lifestyles would surely be enormous. Few studies of the likely consequences have been done, but all kinds of activities would be affected. In urban areas, air pollution alerts could become much more frequent and health problems associated with extreme temperatures would be exacerbated. Growing seasons might be extended, but many crops are vulnerable to temperature abnormalities during critical periods in their growth and the net result could be devastating for U.S. agriculture. Electric utilities would have much greater summer and lower winter demands, requiring radical changes in planning. Some areas dependent on winter recreation might suffer serious losses.

The changes in climate that would accompany this uneven warming process would in some ways have still more profound consequences. A recent analysis of likely changes in seasonal soil moisture concluded that, despite uncertainties, there is strong evidence for summer reduction and winter enhancement of soil wetness over large areas of the Great Plains and Western Europe.[3] The authors note that a "warm climate anomaly" may have been responsible for the 1930s dust bowl--truly a minor variation in contrast to what a global warming will be like.

The effects of reductions in stratospheric ozone have received very little study but it is known that even small changes lead to thousands of new skin cancers. Harmful effects on the human immune system are also suspected as well as large economic losses due to accelerated damage to plastics and damage to some commercially valuable animals.

These changes, worrisome as they are, presume a gradual or largely linear process of change. In fact, scientists recognize that there may be critical points or even "mode switches" associated with changes in temperature and atmospheric trace gases that could lead to rapid, dramatic changes in climate. As the DOE state of the art report states, "The assumption that CO_2-climate change will be gradual and predictable is not unequivocally supported by evidence in the geologic record. . . . The ice-core CO_2 record contains evidence for more rapid, concurrent changes in both CO_2 and climate on time scales on the order of a century.

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[3] S. Manabe and R. Wetherald, "Reduction in Summer Soil Wetness Induced by an Increase in Atmospheric Carbon Dioxide", Science, Vol. 232, May 2, 1986, pp. 626-28.

These past atmospheric CO_2 shifts are comparable to anthropogenic changes brought about since the early 19th century."[4]

One possible cause of accelerated change results from the role of the oceans in the uptake of carbon; they act as a major "sink" for CO_2. If the upper layer of the oceans becomes saturated with increasing CO_2, the fraction remaining in the air would rise sharply and global warming would accelerate. Scientists consider such a scenario a serious concern when high concentrations of CO_2 are reached.[5]

Another possible source of greenhouse acceleration arises from the potential consequences of higher concentrations of carbon dioxide for plant and bacterial respiration.

Higher concentrations of carbon dioxide will result in both increased plant growth and increased respiration of bacteria in soils. Some scientists believe that this process of increased respiration will result in a further increase in the amount of CO_2 in the atmosphere, thereby providing another source of nonlinearity.

The recent discovery of an "ozone hole" during springtime in the Antarctic provides a dramatic illustration of a change in the atmosphere occurring in a nonlinear fashion. Since the late 1970s, springtime ozone has dropped more than 40 percent. This change was not predicted and currently cannot be explained.

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[4] J. Trabalka, *Human Alterations of the Global Carbon Cycle and the Projected Future*, *op.cit.* at 282.

[5] J. Trabalka, *Human Alterations of the Global Carbon Cycle and the Projected Future*, *op.cit.* at 281.

The global increase in atmospheric chlorine due to emission of CFCs since the 1970s is thought by some but not all experts to be involved. Whatever the cause, such events give us further reason for caution with respect to the risks of conducting a giant global experiment in the atmosphere.

The lesson we draw from this brief scientific review is that conventional approaches to problem solving are inadequate to address what we are talking about today. For example, references to traditionally valuable methods of calculating "costs and benefits" may trivialize risks so all-encompassing. The greenhouse and ozone issues--and how we do or do not handle them--will affect all of humanity for generations to come.

Climate Change Up Close

Some problems are almost too overwhelming to comprehend in terms relevant to our daily lives. Nuclear war is the classic example; because it is so frightening, there is a tendency to avoid talking about it. Arguably this is a large part of the problem. Likewise, the profound changes implied by climate and ozone change may lead us to look away or seek excuses for delay.

This reluctance to face the issues squarely is aggravated by the fact that existing knowledge does not delineate localized consequences of climate change beyond seasonal descriptions of shifts in precipitation across very large regions. In the absence of detailed predictions of the consequences of climate change for subregions of the world and the United States, it may be helpful to illustrate how sensitive our lives are to relatively minor changes in temperature and climate. Perspective can be achieved by looking at recent climate related disasters associated with very modest existing climate "extremes." While the chances that any one of these configurations will occur in a warmer world may be more or less, they illustrate the ways in which climate change will increasingly become evident to mankind.

The Sahelian droughts in Africa have been perhaps the most devastating of any climate related catastrophes of our time. Millions have starved to death and malnutrition has plagued the drought's survivors. There is some indication that the worst of this drought period has ended--for now. Yet this region is within a zone potentially subject to increased summer dryness as a result of global warming.

Extreme weather events have been wreaking havoc in many parts of the United States this year. In Utah and the Great Lakes region, record rain and snow have caused extensive flooding, threatening an interstate highway and airport near Salt Lake City and forcing hundreds of families to evacuate. The Great Lakes have risen about 2 feet; this may displace entire communities and inflict damage of more than $1 billion. Meanwhile, large parts of the Southeast experienced record droughts leading to extensive forest fires and stunting crops.

We also experience terrible human and economic losses whenever summer temperatures are very high. The unusually hot summer of 1980, for example, was estimated to have a role in more than a thousand deaths and to have cost billions of dollars in agricultural losses, increased energy use, and other indirect costs.

The water supplies of much of the U.S. population are already susceptible to stress from existing weather extremes. New York City, for example, suffered an extended drought last year despite adequate rainfall in the city proper because of its dependence on precipitation patterns in the Catskill region 100 miles away.

One of the most serious weather anomalies is the El Nino, the extended appearance of warm water off the coast of Peru and Ecuador associated with an increase in the high pressure in the western Pacific and a parallel drop in the eastern Pacific. El Ninos have been associated with a catastrophic reduction in anchovy harvests, severe droughts in some regions, and heavy flooding in others. The causes of El Nino are under intense investigation.[6] According to one current theory, the heat content of the upper equatorial ocean is a leading indicator of the phenomenon. The possible effect of a general warming of the oceans on this process is unknown, but it is profoundly troubling.

No one can yet say precisely what problems will be caused by the greenhouse effect and ozone modification. My point is rather to emphasize how susceptible we are to even relatively minor changes in temperature and precipitation, much less radical changes in the global climate system. Even such minor changes as we are experiencing now have large costs attached to them and affect economic decisions being made today. As the distinguished scientists at the Villach meeting concluded,

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[6] C. Ramage, "El Nino", Scientific American, Vol. 254, June 1986, pp. 76-83.

> "Many important economic and social decisions are being made today on major irrigation, hydro-power and other water projects; on drought and agricultural land use; on structural designs and coastal engineering projects; and on energy planning, all based on assumptions about climate a number of decades into the future. Most such decisions assume that past climatic data, without modification, are a reliable guide to the future. This is no longer a good assumption since the increases of greenhouse gases are expected to cause a significant warming of the global climate."

Early Indicators

One challenge of greenhouse warming and ozone modification is that we must act before the dimensions of the problems are fully known or risk irreversible, catastrophic changes. Extended debates on control strategies and cost allocation schemes will hardly be relevant once an unprecedented global warming has ocurred. As William Ruckelshaus has said of the greenhouse problem, "The ultimate danger is that by remaining reliant on the 'catastrophe theory of planning' in an era producing catastrophes of a magnitude greater than in the past, we can place our institutions in situations where precipitate action is the sole option--and it is then that our institutions themselves can be imperilled and individual rights overrun."[7]

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[7] M. Barth and J. Titus, Greenhouse Effect and Sea Level Rise (1984), p.x (foreward).

Given that we must act in advance of a sizable global warming, it is fortunate that we are not dependent solely on unproven theories. Empirical indicators provide physical proof of global warming and ozone modification. A 25 percent increase in the atmospheric concentration of CO_2 in the past century and a build-up of CFCs and other trace gases are measured facts. The warming effect of atmospheric carbon dioxide is a well-establiished fact. Without water and carbon dioxide in our atmosphere, the earth would be a frigid zero degrees. As a result of high CO_2 concentrations in its atmosphere, Venus has temperatures of 800 degrees F. The warming effect of high CO_2 atmospheres is not open to argument.

Twentieth century temperature trends also are consistent with a global warming. Northern hemisphere temperatures have shown an upward trend, interrupted inexplicably by a cooling between 1940 and 1965. A survey of Southern hemisphere temperatures has recently become available; this record may be a more reliable indicator than Northern hemisphere trends because of the smaller distorting effect of land mass.[8] It shows a clearer warming trend. Significantly, the three warmest years of the entire record (since 1951) were 1980, '81, and '83. Reviewing these temperature trends and sea level changes, a recent DOE report concludes that "Model projections of the climatic response to an increased CO_2 concentration indicate that such changes should be expected. The apparent agreement strongly suggests a causal relation."[9]

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[8] P. D. Jones et al., A Grid-Point Surface Air Temperature Data Set for the Southern Hemisphere, (TR027, DOE/EV/10098-6, 1986).

Confirming evidence, recently documented, is also found in the dramatic retreat of European glaciers since 1850. A new study concludes that these glaciers may be extremely vulnerable to the presence of infrared-absorbing gases, and that the observed retreat can be explained by the increase of greenhouse gases. "Valley glaciers can be considered as very good indicators of climatic change induced by small shifts in the long-term radiation balance."[10]

Finally, the reality of rapid changes in stratospheric ozone has been dramatically demonstrated by the accelerating spring-time reduction of ozone over the Antarctic since the late 1950's. NASA's recent report to Congress[11] also describes statistically significant measured reductions in ozone at middle and high levels of the stratosphere around the earth generally, although this result is subject to some uncertainty.

First Steps

This hearing is momentous because it is the first to ask not only "what is the problem", but "what can we do?" It is tempting to throw up one's hands in despair upon realizing the full dimensions of these climate problems. They are truly global, and only an international response can be completely effective; substantial economic interests will be adversely affected; and the actions which are needed must precede a clear picture of the risks. But many modest steps are feasible and advisable in the near term, and, if taken, will make a difference in the outcome.

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[9] M. MacCracken and F. Luther, Detecting the Climatic Effects of Increasing Carbon Dioxide (U.S. DOE, 1985), p.xxvi.

[10] J. Oerlemans, "Glaciers as Indicators of a Carbon Dioxide Warming," Nature, Vol. 320, 17 April 1986, pp. 607-609.

[11] National Aeronautics and Space Administration, Present State of Knowledge of the Upper Atmosphere: An Assessment Report (January 1986).

Of course, more research is urgently needed. The fact that the National Oceanic and Atmospheric Administration (NOAA) has still not committed to continued funding of a critical ozone-measuring satellite is a shocking example of the fragile support for even the most essential research on these issues. A major program on the role of the oceans in climate change ought to be another high priority. There is also very little support for research on the impacts of changes in climate and ozone. Despite the present budgetary pressures, the seriousness of the issues surely justifies funding at least double current levels.

However valuable, research alone is not the answer. Many of these issues will require decades to resolve. The National Academy of Sciences recently completed a preliminary study of the components necessary for an International Geosphere-Biosphere Program.[12] Their review touches on many of the issues relevant to a detailed understanding of the causes and consequences of climate change. While noting that such an effort was unimaginable

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[12] Natural Research Council, Global Change in the Geosphere-Biosphere (1986).

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even a decade ago, they also recognize and state: "Nor can it be completed in the next 10 years or the next 20." Again, we are likely to experience serious effects before we understand them.

While research continues, government action--or inaction--will have a great effect on the rate of growth in emissions of trace gases. The increase in energy prices caused by OPEC greatly reduced energy growth rates and therefore carbon dioxide emissions. The end of the global recession and the recent drop in energy prices have combined to hasten growth in CO_2 emissions once again. If this trend continues, the consequences of climate change will be felt sooner and demand more precipitous action. If, conversely, we curtail emissions of CFCs and growth in CO_2-producing energy remains moderate, we can limit the extent of the effects and delay the most serious changes for decades.

The timing of action will also have considerable impact on how precipitous actions must ultimately be, and therefore how difficult and costly. As the DOE state of the art report notes,

> Planning for potential development and implementation of alternative environmentally benign energy sources should be undertaken well in advance of the time when a response may be needed to lessen the political, economic, and other human impacts of these changes.[13]

The faster emissions increase and the longer they are allowed to accumulate, the more difficult it becomes to stay within any proposed future limit for the atmospheric concentration of trace gases. Even relatively modest short-term actions may therefore make an important long-term difference if they help to avoid rapid or sustained growth of gas concentrations. Restrictions on aerosol uses of CFCs adopted in the U.S. and Europe are a good example. These actions did not stop the increase in atmospheric concentration of CFCs or the growth in other uses, but they reduced the rate of buildup. In the absence of these actions, the problems we have discussed today would otherwise be more imminent and the necessary responses more severe.

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[13] J. Trabalka, Human Alterations of the Global Carbon Cycle and the Projected Future, op.cit. at 282.

Several steps should be taken immediately. One is to place these issues much higher on the world's agenda. Political leadership is necessary at the highest levels. We strongly support Senator Chafee's recent recommendation to include climate change on the agenda for the next U.S. summit meeting with the Soviet Union. Similar efforts should also be made to involve the People's Republic of China, which now uses as much coal as the U.S. and USSR, and which plans rapid future coal development as the basis for its economic growth.

International political leadership is also necessary to promote cooperative policies to restrict continued growth in CFC emissions. The most recent estimates are that roughly a third of global CFC use still goes for aerosol propellants, for which substitutes are readily available. It is in our interest to do all we can to encourage other governments to join the U.S. in reducing CFC emissions. There are ongoing efforts toward this end resulting from procedures created by the Vienna Convention for the Protection of the Ozone Layer. However, the highest levels of government should be involved in expressing the depth of our concern to other countries.

Much more should also be done to promote broader public and official awareness of these issues and their consequences. Climate change should be an important consideration in the planning done by government agencies. While NASA, NOAA, EPA, and DOE already have some climate and ozone programs, the results of these programs are rarely taken into account in other activities or broader agency planning. For example, DOE does not consider climate implications of coal leasing, "clean coal" technologies, or electricity growth. Worse, many other departments with seriously threatened interests--Defense, Agriculture, Interior, State, Transportation, and Federal Emergency Management Agency (FEMA), for example--have no internal expertise or process for analyzing these issues.

In January, we wrote to Alan Hill, Chairman of the Council on Environmental Quality, proposing that CEQ advise agencies of their responsibilities to consider these issues. We are told that our letter was referred to Mary Walker, Assistant Secretary for Environment, Safety & Health at the Department of Energy, from whom we have received no response.

The Environmental Protection Agency has done the only policy analysis of climate change and ozone modification. Currently EPA is conducting an analysis of strategies for achieving further reductions in emissions of CFCs in response to a lawsuit brought to enforce the ozone protection provisions of the Clean Air Act. Similar analysis should be initiated to look at options for staying within potentially desirable limits on the buildup of other greenhouse gases.

The World Resources Institute is preparing its own assessment of the policy changes required to limit the accumulation of greenhouse gases to levels consistent with substantial economic and population growth. While the records of inaction to date--and the complexity of the problem scientifically and politically--give little reason for confidence, it is clear that a combination of energy efficiency investments, renewable energy development, strong controls on CFC emissions, and a halt to global deforestation could allow the world to avoid the equivalent of a doubling in the CO_2 concentration for many decades.

Nevertheless, some significant climate change is unavoidable. Past emissions of these greenhouse gases have already committed the atmosphere to a warming that may be as much as 2 degrees Fahrenheit.

U.S. support for a major international effort to halt tropical deforestation ought to be undertaken for many reasons, but the benefit of reducing the buildup of carbon dioxide could be substantial. The biotic contribution to CO_2, much of it due to tropical deforestation[14], is as much as 40 percent of the contribution from fossil fuels. Tropical Forests: A Call for Action, the report of an international task force convened by the World Resources Institute, The World Bank, and the United Naitons Development Programme, outlines in detail the necessary steps to halt this destruction.

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[14] Richard Houghton, "Uncertainties in Estimating the Terrestrial Biospheric CO_2 Release from the Tropics", CDIC Communications, Spring 1986, pp. 4-5.

We should also accelerate support for development of more efficient technologies and renewable energy systems. Unfortunately, support for such initiatives has declined dramatically in the U.S. over the last five years. Moreover, the short-term decline in energy prices has slowed some of the private sector interest in energy alternatives as well. Strong government leadership will be necessary to reverse this self-defeating trend.

Finally, policies to more directly limit carbon dioxide emissions may also soon be necessary, and we should initiate an assessment of the policies which we may not be able to do without. One logical direction is to consider a carbon tax, with funds raised going to plant trees and promote energy conservation. Analysis of such policies should begin today, so that decisions concerning their implementation can be made in the near future.

Testimony Before Subcommittee on Environmental Pollution of the Senate Committee on Environment and Public Works
10 June 1986

by

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Introduction

I will discuss the relationship between the ocean and the continuing rise in levels of atmospheric carbon dioxide (CO-2). That the ocean is important in understanding the effects of the CO-2 rise has been known for a long time. But the extent to which the oceanic effects introduce very great uncertainty has not been much appreciated.

Rising concentrations of carbon dioxide and other trace gases with 'greenhouse' properties are now widely recognized as representing an 'experiment' with our environemnt with potentially catastrophic consequences in the longer term. The weight of scientific understanding strongly supports the conclusion that the atmosphere will warm considerably (an *average* change of about 2° C, with regional changes probably much larger than this average), and with a greater warming near the poles than at the equator. Although no one can guarantee this outcome, it is widely accepted as the most likely change.

What is the role of the ocean in the actual result? In general terms, the ocean plays a number of parts. Much of the carbon dioxide that is added to the atmosphere ultimately finds its way into the ocean. To the extent that CO-2 is dissolved in the *deep* ocean, it no longer has a greenhouse effect and thus reduces the effective atmospheric warming. The fraction of the CO-2 that will eventually be locked up in the ocean can be calculated on the basis of chemical equilibrium and is not controversial. Unfortunately, the time required to reach this final equilibrium state is extremely long (probably thousands of years) and so it is not particularly relevant to the present discussion.

In the calculations made by meteorologists, the ocean is assumed to take up a certain fraction of the CO-2 currently going into the atmosphere and to continue to do so indefinitely. This fraction has been estimated by both observing the fraction of the CO-2 which is staying in the atmosphere and relegating the remainder to the ocean, and by observing the chemical distribution in the present day ocean and converting that to CO-2 uptake rates.

The ocean thus removes part of the carbon dioxide and the rate at which it does so in the near-term will to a great extent determine the rate at which the atmosphere warms. Should the ocean remove a great deal more than is currently estimated, the warming will be delayed; should it take up a good deal less, the warming will come sooner.

But the ocean plays a number of less direct roles whose consequences also need to be understood. As the atmosphere warms, it in turn warms the ocean. Not only is the ocean a sink for CO-2, it is also a sink for the increasing heat in the atmosphere. When heat is placed

SCHEMATIC OCEAN CIRCULATION (NOW)

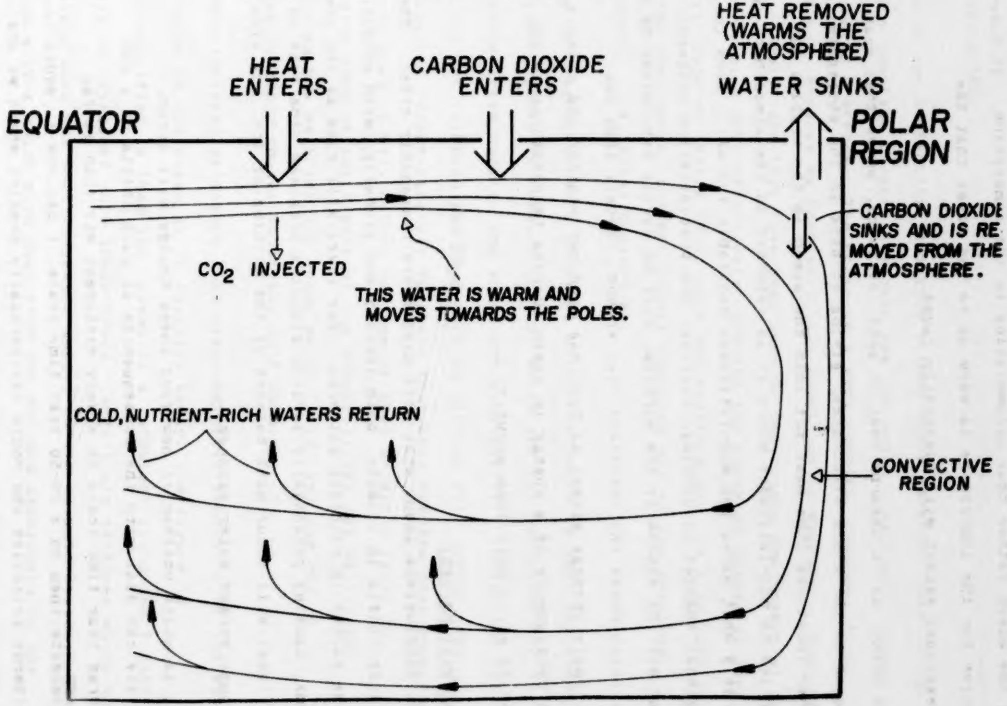

HEAT ENTERS
CARBON DIOXIDE ENTERS
HEAT REMOVED (WARMS THE ATMOSPHERE)
WATER SINKS
EQUATOR
POLAR REGION
CO_2 INJECTED
THIS WATER IS WARM AND MOVES TOWARDS THE POLES.
CARBON DIOXIDE SINKS AND IS REMOVED FROM THE ATMOSPHERE.
COLD, NUTRIENT-RICH WATERS RETURN
CONVECTIVE REGION

FIGURE 1

in the ocean rather than accumulating in the atmosphere, it takes longer for the atmosphere to warm up to the level that the greenhouse effect will eventually cause.

The ocean, as it absorbs heat in some locations, moves that heat around as the fluid circulates, giving it back to the atmosphere in other locations (the heat put into the ocean in the tropics and carried to mid-latitudes where it is returned to the atmosphere is largely what makes the mid-latitudes habitable for us). Thus the regional changes in warming, cooling, and precipitation patterns that will be caused by the warming, will be partly determined by how the ocean moves the increased heat around. Recall that the extremely intense effect El Nino has upon our weather and climate is the consequence of a change in ocean surface temperatures in the tropics of no more than about 1° C.

What Will Happen?

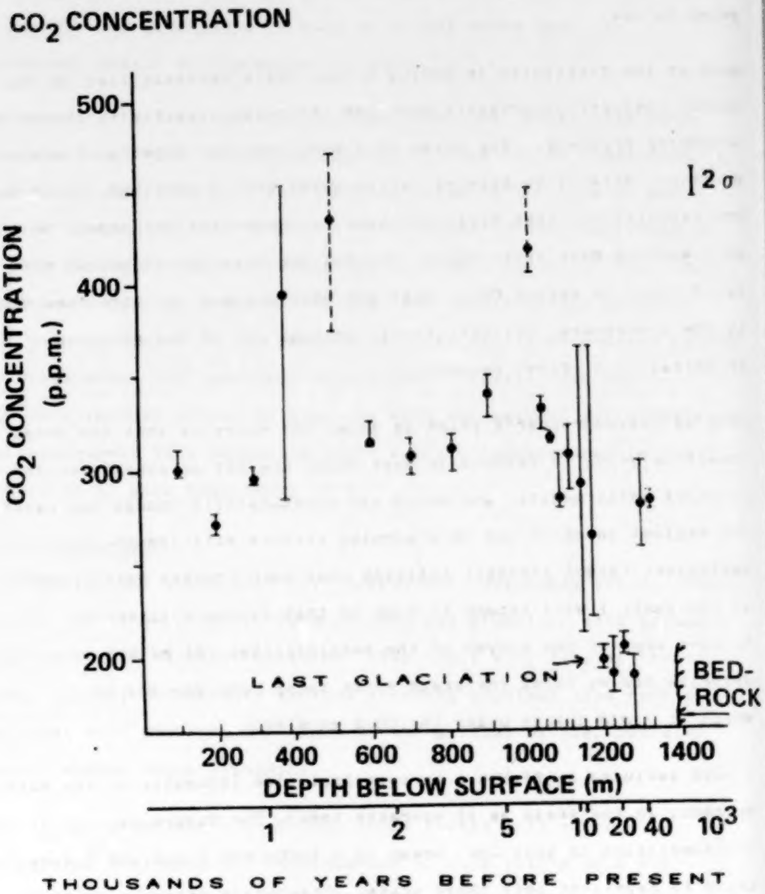
Some conclusions about what will happen are reasonably clear. There will be shifts in climate, both locally and globally, with probable large shifts in rainfall patterns. Sea level will rise as the ocean warms, causing potentially serious flooding problems (the rise in sea level will occur both because of the melting of ice, but also because warmed water expands).

What is quite unclear is *how fast* these things will occur. Society can deal with the consequences of such shifts on a 200 hundred year time scale in a very different way than it can accomodate them on a 20-50 year time scale. I believe it would be a foolhardy scientist who would categorically predict which we are going to see.

Much of the difficulty in making a time scale forecast lies in the nearly complete uncertainty over how the ocean itself will change as a warming proceeds. The ocean is a very complex, flowing, fluid machine. Because we know so little about how it operates, most of the calculations that have been done to understand the impact of the CO-2 warming have effectively treated the ocean as though it were a solid--able to absorb CO-2, heat and moisture and to give them back to the atmosphere, but not itself changing any of its existing dynamical (i.e. flow) properties.

From an oceanographer's point of view, the worry is that the ocean itself is going to respond in ways which are not accounted for in existing ocean models, and which can substansially change the rates and regions in which the CO-2 warming effects will appear. The geological record strongly suggests that such changes have occurred in the past; I will return to some of that evidence later on. To give some of the flavor of the possibilities let me try to describe how we think the ocean works today, and *one way* in which it *could* change under the CO-2 warming.

I have included as figure 1 an oversimplified schematic of the water movement in the ocean as it operates today. The figure is oversimplified in that the ocean is a turbulent fluid and I have tried to represent only those gross, large-scale features which we believe have the most immediate impact on our climate system. The ocean waters which gain heat from the sun and atmosphere in the tropics tend to move on average toward the polar regions. In the



(After Neftel, Oeschger, Schwander, Stauffer, and Zumbrunn, Nature, 1982).

Figure 2

polar regions, the atmosphere regains that heat, leaving behind water which is extremely cold and salty, so cold and salty that it tends to sink to the ocean floor in a process we call "convection". This sinking process is exceedingly important: it is the sinking which sucks the warm water up from the south to replace the water which has gone to great depths. One of the important reasons that western Europe and the US west coast are so warm is that the ocean gets so cold to the north of them, in a process leading to convection, which brings warm water flowing in from the south. Anything which changes the rate at which convection occurs will change the global climate.

Furthermore, water which is in contact with the atmosphere, i.e. the warm water being sucked up from the south, becomes saturated in CO-2. Once it is saturated, it can take no more out of the atmosphere. But when the saturated water water sinks, it injects CO-2 into the deep ocean, thus removing it from the atmosphere and bringing unsaturated water to the surface and speeding up the CO-2 removal from the atmosphere. Any process which changes the speed with which the ocean convects, will affect the rate of CO-2 buildup in the atmosphere.

In addition, the water which moves poleward along and near the surface is in the region of the active biological productivity. Plant and animal production in these near-surface waters depletes it of the nutrients essential for biological activity. The cycle is maintained when water which has sunk at high latitudes in the convective process is eventually, and many years later, returned to near-surface, enriched in nutrients. Anything which reduces the convection rate, ultimately reduces the depth to which the water descends, the rate at which water returns to the surface, and hence, ultimately, the supply of nutrients to near-surface life.

Consider now what *could* happen in a warming.

We suppose that the near-surface layers of the ocean become somewhat warmer, at least intially and that the temperature increase in both the atmosphere and ocean are somewhat greater near the poles. We expect that the wind-driving on the ocean surface will be reduced, because the extensive wind systems (trades and westerlies) are largely due to the great temperature contrast between high and low latitudes. With the wind driving reduced, the rates at which the ocean water moves will in turn be reduced. The combination of decreased wind driving, and somewhat warmer near surface waters and air temperatures, implies that water now sinking at high latitudes would not get as heavy as today, and therefore would not sink as fast, or as deep, thus further reducing the rate of ocean circulation. The ocean would be able to take up less heat than it now does (unable then to push it downward) and less CO-2 (also unable to push it downward). The CO-2 content of the atmosphere would rise more rapidly than now envisioned. The story is made complicated with feedbacks I choose not to speculate about now, but involving greater sealevel rises, melting of ice, further interaction with atmospheric temperature, precipitation, cloud cover....

What I have outlined is of course speculative; but it is possible.

The further complications are nearly endless. Suppose what I described should happen in large part. Would Europe and the western US get warmer, as one might think, or colder? As I have already noted these places are largely warmed today, somewhat paradoxically, because they lie south of much colder regions, which force the ocean to convect, thus bringing warm water flowing by. But suppose the convective process is slowed down? The local water temperature is a complex result of both local air-sea exchanges and the global flow of water. It is quite possible in the local adjustments taking place, that surface tempearatures would locally decline. One hesitates to be definite in such a problem where our working knowledge of the system is so primitive.

I would note that the historical record, particularly the measurements of CO-2 in ice cores (see figure 2) suggest that in the past rapid fluctuations of atmospheric CO-2 have occurred; these fluctuations implicate the ocean as a major component. The figure shows that during the last glaciation, there was apparently much less CO-2 in the atmosphere (air is trapped in the freezing ice and provides a record of atmospheric concentrations at that time). Whether the CO-2 change was cause or effect, or somewhat of both as seems most likely, is unclear. But the apparent change is so rapid, only changes in the ocean seem likely to be able to explain it.

Why Can't We Predict Better?

The models used by meteoriogists to study the impact of CO-2, as described above, generally make no provision for changes in the ocean itself. Given our current state of knowledge about the ocean, these models are the most sensible ones to use, as there would be little or no credibility to anything more complex.

The chief problem faced by oceanographers in attempting to make believable models of ocean behavior has been the great difficulty of observing the system. Few scientists, much less laymen, have any understanding that at present the ocean is essentially *unobserved* at all. The ocean is a fluid covering two thirds of the earth's surface and having a complexity rivalling that of the atmosphere. Because we live only at the edges of this fluid, rather than right in it as we do the atmosphere, few people understand that the ocean has both a weather, and a climate, and is changing in complicated ways from day to day, that go unseen, unmeasured, and unremarked.

Besides the fact that we live on the upper edge of the ocean, rather than within it, there are some fundamental difficulties. No government agency has ever undertaken to observe the ocean as a whole, and in the detail with which it would be necessary. (The global atmospheric observation system is a byproduct of the needs perceived by governments to forcast the weather). Oceanic observations lie in the hands of academics like myself who cannot sustain large scale operational systems. Furthermore, one cannot send radio waves through the ocean, a physical condition which greatly complicates the entire observational strategy.

At the present time then, trying to understand what the ocean will do under the CO-2 transient is akin to forcasting next week's weather having no idea at all about today's.

On the other hand, we have finally reached a scientific and technical level of capability in which obtaining the necessary observations is not only feasible, but is economically practical. Under the auspices of the World Climate Research Program, the global community of oceanographers is putting together a program, called the World Ocean Circulation Experiment (or WOCE) whose purpose is to create an observational and modelling program capable of addressing the concerns about the ocean and the CO-2 problem as well as the more general questions about the ocean in climate.

This program, which should have begun already, is intended to observe the ocean sufficiently densely for a 5+ year period so that at the end of that time, we would have a working model of the ocean as it exists today, with sufficient confidence to use such a model for determining how the system is likely to change. The elements of WOCE involve a minimum of two US satellites (others will come from Europe and Japan), and modernization of our more conventional observing systems based upon ships and in-the-water instrumentation. Only one of the two US satellites has been funded (the second, a NASA mission called TOPEX is now before the Congress as part of the Administration's FY1987 budget proposal). A third mission, to measure the earth's gravity with high accuracy would be very desireable. The funding necessary for the NSF to re-build our sea-going capability from its past 15 years of decline has also not been funded (a proposal to do so, in part, is also before the Congress).

Without such a program, we will never be in a position to predict what is going to happen, whether benign or dire, nor the rates at which the changes will occur. The scientific facts of life are that too little is known about the ocean to make any reliable estimate of the changes that will occur there during the CO-2 rise. That serious environmental changes owing to the CO-2 will happen is not in doubt; the pace at which they will happen is very uncertain. The consequences are that policy can only be made in a vacuum, but a remedy is at hand.

TESTIMONY

to

Senator John H. Chafee, Chairman
Committee on Environment and Public Works
United States Senate
Washington, D.C.

on

June 10, 1986

by

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Background

I have a Ph.D. in Environmental Sciences (Earth Science Processes) from the University of Virginia. I have authored/edited 6 books on coastal processes and geomorphology (including the Barrier Island Handbook) and have written over 100 scientific articles and reports. Recently, I have conducted research on the quantification of historical shoreline changes and projection of future rates of beach erosion. I am a member of the National Academy of Sciences Committee on the Engineering Effects of Accelerated Sea-Level Rise.

Introduction

Throughout geologic history sea level has fluctuated greatly. During the last ice age (approximately 15,000 years ago), sea level was as much as 100 meters below present levels. The earth at this time was about five degrees celsius colder than today. During warm interglacial periods, sea level has been at times several meters higher than present. Because of the historic relationship between climate and sea level position, it is expected that anthropogenic (human-induced) global warming could cause a significant rise in sea level. Warmer temperatures could expand ocean waters, melt glaciers, and eventually cause the disintegration of the West Antarctic ice sheet.

Climate can effect sea level position by heating and thereby expanding (or conversely cooling and contracting) surface sea water. This process can occur over relatively short periods of time. At present the mid-latitude mountain glaciers are still retreating. Although most of the glaciers have melted since the last ice age, there is still enough water in polar glaciers to raise sea level by more than 70 meters. Over longer periods of time, significant rises in sea level could be caused by disintegration of the West Antarctic ice sheet, which is marine based and subject to temperature increases.

In the last century, surface temperatures have shown a gradual increase based on National Weather Service data, and tide gauges have recorded about a 30 centimeter (one foot) rise along the U.S. Atlantic Coast. Some of this relative rise in sea level (relative to the land surface) can be explained by the natural compaction and subsidence of unconsolidated coastal sediments. However, part of this rise (at least 12 cm) can be attributed to thermal expansion of surface ocean waters and glacier recession, resulting from the observed warming of 0.4° C during the last century. Figure 1 shows the strong correlation between global temperature and sea-level rise.

Future Sea-Level Rise

Concern about a possible acceleration in the rate of sea-level rise stems from measurements showing that concentrations of carbon dioxide and other "greenhouse" gases produced by human activities are increasing in the atmosphere. Because these gases absorb (trap) long-wave radiation (heat) in the atmosphere, it is generally expected that the earth will warm substantially in the future. The National Academy of Sciences has convened two panels to review all the evidence and concluded that warming will take place.

There is no doubt that the concentration of greenhouse gases is increasing and will do so in the foreseeable future. However, considerable uncertainty exists regarding the amount of warming; it is generally agreed that a doubling of the greenhouse gases will raise the earth's average surface temperature by about 1° C if nothing else changed. It appears that most of the climatic factors will amplify the direct effects, but some negative feedbacks (such as increased cloud cover to offset part of the warming) cannot be ruled out. Nevertheless, two panels of the National Academy of Sciences (NAS) have concluded that a doubling of greenhouse gases will eventually induce a warming between 1.5° and 4.5° C (3°-8° F).

Based on current trends, Revelle (1983) estimated that sea level could rise by 70 cm (30 cm due to thermal expansion; the balance attributed to glacial melting) by the next century. There have been a range of estimates made by NAS, EPA, and various scientific investigators. The recent NAS Polar Research Board Report (1985) placed the total rise at between 50 and 200 cm by the year 2100. This range lies within the same values derived independently by the EPA. The estimated magnitude and timing of increased sea-level rise are illustrated by Figure 2.

Effects of Sea-Level Rise

The principal effects of sea-level rise are increased tidal flooding and wave-induced erosion. Salt-water intrusion can also be a problem in some areas, particularly affecting surface waters.

1. Tidal Flooding

A rise in sea level represents a raising of the water base level. Therefore, storm waves and surges can reach higher and further inland. This can result in accelerated beach erosion as explained later, and major flooding will occur more often. For example, "100-year" storms can occur on a 10 year averaged basis by virtue of higher base levels when considering frequency-magnitude relationships of coastal flooding.

The most significant impact of higher sea-levels will be the submergence of coastal wetlands. Intertidal salt marshes can adapt only to relatively moderate rates of sea level rise; rapid increases in sea level can literally drown these wetlands, converting them to shallow bodies of open water. It is worth noting that the present U.S. tidal marshes postdate the previous maximum rate of sea level rise during the Holocene (since the last ice age), when sea level rose approximately 1 meter per century (1 cm per year).

Much of the Louisiana coastal zone is experiencing a rapid relative rise in sea level (up to 1 cm per year) largely due to human-induced subsidence. Without adequate supplies of sediment to raise the elevation of the marsh surface, these wetland plants become water-logged and eventually die. Presently, Louisiana is losing four acres of marsh per day, and entire parishes (counties) will be under water within the next 100 years. During periods of only gradual sea-level rise, plant-generated (organic) sediment and inorganic materials from rivers, uplands, and the sea could maintain the marsh surface plain relative to sea level positions. However, the Louisiana marshes dramatically illustrate the problem of rapid water level changes, and can serve as useful analogs of what will happen elsewhere along the U.S. coastline with accelerated sea-level rise.

A one-meter rise in sea level could drown most of the wetlands without necessarily creating new marshes inland. Even in natural areas the marshes will contract because of the sloping nature of the land above the marsh plain (Figure 3). Where marshes are backed by urbanized areas, such as along much of the Long Island, N.Y. coast for example, these habitats will be squeezed out with future sea-level rise.

2. Coastal Erosion

Sea level is one of the principal determinants of shoreline position. There are several reasons why sea-level rise would induce beach erosion or accelerate on-going shore retreat: (1) waves can get closer to shore before dissipating their energy by breaking, (2) deeper water decreases wave refraction and thus increases the capacity for longshore transport, and (3) with a higher water level, the wave and current erosion processes are acting further up the beach profile, causing a readjustment of that profile.

Most sandy shorelines are presently eroding on a worldwide basis. Historical records indicate the prevalence of shore retreat during at least the past century. The National Shoreline Study by the U.S. Army Corps of Engineers (1971) was the first overall national appraisal of shore erosion problems. This study showed that 43 percent of the shoreline is undergoing significant erosion, excluding Alaska. In fact, this report indicates that most all of the U.S. ocean shoreline is undergoing erosion (excluding hard-rock coasts). Accretion is restricted to coastal areas where locally excess sediment is supplied by river sources or where the land is being elevated by tectonic (earthquake or glacial rebound) activity.

There are several different approaches that can be used to project shore retreat with sea-level rise. The simplest approach is to apply the "drowned valley" concept, whereby pre-existing topography is used to project new shorelines. Slope is the controlling variable, such that gently-sloping shores will undergo a much broader area of inundation for a given sea-level rise compared to steep-sloped areas. This is the preferred methodology to apply to immobile (rocky or armored) coasts or for sheltered coasts, such as small bays and estuaries.

The other approaches that have been employed to date are largely based on the erosional potential of sea-level rise: (1) extrapolation of historical trend, (2) Bruun Rule, (3) sediment budget analysis, and (4) the dynamic equilibrium model. These methodologies, including applications and limitations, will be discussed in a forthcoming National Academy of Sciences report (in preparation). A severe limitation to our forecasting future erosion rates is lack of good quantitative data on historical rates of shore retreat for much of the U.S. coastline. Basically, a comparable range of rates of shore retreat are predicted by these different approaches.

For open ocean sandy beaches, at least a doubling and perhaps a five-fold increase in erosion rates can be forecast, depending upon the realized rates of accelerated sea-level rise. Our urbanized beaches are already critically narrow and continuing to erode, and accelerated sea-level rise will exacerbate an already serious problem. Presently many recreational beaches are being nourished (e.g., Miami Beach, FL, 1980s, $65 million) or will be nourished in the near future (e.g., Ocean City, MD, 1987, $30 million, first cost). More beaches will have to be replenished in the future, more often, in order to maintain their recreational quality and provide storm protection for the landward-flanking coastal development.

Summary

1. There appears to be a strong co-relationship between earth warming and sea-level rise. In geologic time, the last time the temperature increased 1-2° C, the ocean levels rose several meters. During the past century, sea level has risen about one foot (30 cm) of which about one-half can be attributed to global causes, concurrent with warming of the earth's surface by 0.4° C. The chief uncertainty lies in how rapidly the polar glaciers may melt.

2. Several groups have projected sea-level rise, notably the National Academy of Sciences (NAS) and the Environmental Protection Agency (EPA). Two panels of NAS have been convened and concluded that sea level will increase by 70 cm by 2100 (1983 Revelle report) with the most recent estimates by the NAS-Polar Research Board (1985) ranging from 50 to 200 cm. These ranges are comparable to the most recent (1986) EPA projections of 57-368 cm.

   It is clear that sea levels will rise due to thermal expansion of heated water and melting of mid-latitude glaciers. The present estimates of accelerated sea-level rise are based on these factors. Contributions from the polar ice caps, particularly dissolution of the West Anarctica ice sheet, are less certain in terms of timing and magnitude.

3. Wetlands will be much affected by accelerated sea-level rise, resulting in significant losses (at least 50% and perhaps as much as 80% by the year 2100 according to some nationwide estimates). Wetlands can shift inland,

but their area will drastically shrink due to the sloping nature of the mainland flanking the marsh levels. Where urbanized, the wetlands will be essentially squeezed out of existence. Clearly, some areas will lose more marsh than others, depending upon topographic conditions and anthropogenic controls. It is doubtful if people will be willing to abandon urbanized areas to allow for wetlands invasion concurrent with sea-level rise.

4. Sea-level rise will promote increased coastal erosion. Already approximately 80% of our sandy coastlines are eroding, and accelerated sea-level rise will only exacerbate this critical problem. Rates of shore erosion will probably at least double and may increase five-fold based on the realized rate of water level changes. As a rule of thumb, a one foot (30 cm) rise in sea level will result in 100 feet (30 meters) of erosion along the U.S. Atlantic and Gulf Coasts applying the Bruun Rule. This means that most of our recreational beaches would be lost since so many are already critically narrow. Artificial nourishment is being used to restore beaches, but the costs are high. Accelerated sea-level rise will increase the quantity and frequency of beach restoration projects.

5. It is certain that these potential problems will only worsen in the near future. Within the next 40-50 years, sea level will probably have risen by a foot, resulting in major impacts to coastal environments. Rather than triggering dramatic change, sea-level rise will promote gradual erosion and invariably increase the vulnerability of human development as well as culminate in significant losses of wetlands. These impacts are perhaps more insidious than the short-lived, dramatic storm-induced damages to coastal areas.

Recommendations

1. Shoreline data from historical maps, charts, and aerial photographs needs to be compared by state-of-the-art mapping techniques to yield quantitative rates of beach recession. This information on a national basis is needed to provide a reference for and calibration of projected erosion based on accelerated sea-level rise. At present accurate historical shoreline data exist for only parts of the U.S. coast.

2. Salt marshes are already being lost at alarming rates in some coastal areas (notably in Louisiana and the Blackwater Wildlife Refuge in Maryland). More research is needed to understand the mechanisms of marsh loss, which probably vary on a geographic basis (eg., development of interior ponding at Blackwater vs. the "wetted tissue" model for the Louisiana marshes).

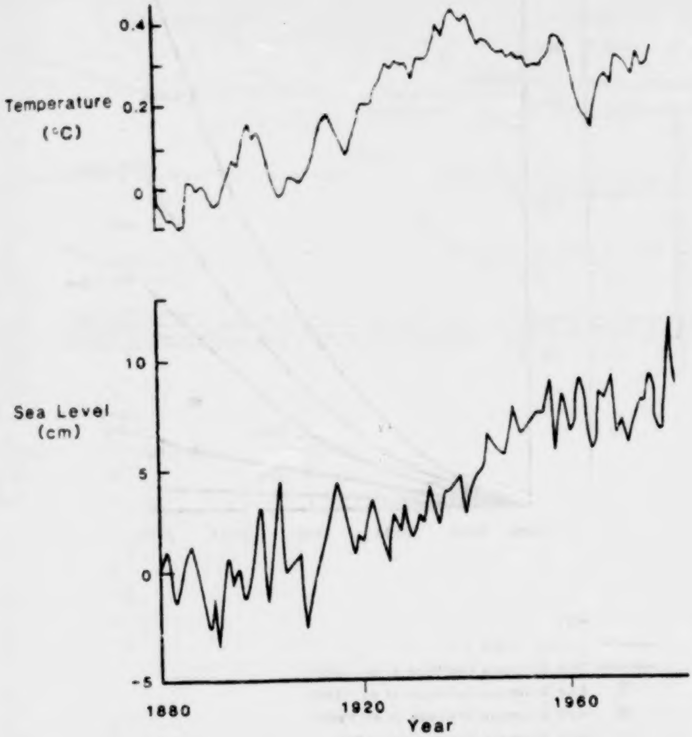
3. An assessment of coastal urbanization along eroding shorelines needs to be made. What are the temporal and spatial (national) trends in terms of continued development and increased vulnerability? How should coastal planning be modified to take into account accelerated sea-level rise?

4. Shore erosion and wetlands loss in association with coastal urbanization are critical research priorities. Academic scientists, who have been largely responsible for our present understanding of these processes, need to receive extended and expanded research monies to provide independent

and objective data. In practical terms, this university research initiative should be supplemented by the relevant federal agencies, including the Corps of Engineers, Fish & Wildlife Service, EPA, and HUD.

FIGURE 1

GLOBAL TEMPERATURES AND SEA LEVEL RISE IN THE LAST CENTURY



Sources: Temperature curve from: HANSEN, J.E., D. JOHNSON, A. LACIS, S. LEBEDEFF, D. RIND, AND G. RUSSELL, 1981. Climate Impact of Increasing Atmospheric Carbon Dioxide. Science 213:957-966. Sea level curve adapted from: GORNITZ, V., S. LEBEDEFF, and J. HANSEN, 1982. Global Sea Level Trend in the Past Century. Science 215:1611-1614.

FIGURE 2 GLOBAL SEA LEVEL RISE SCENARIOS

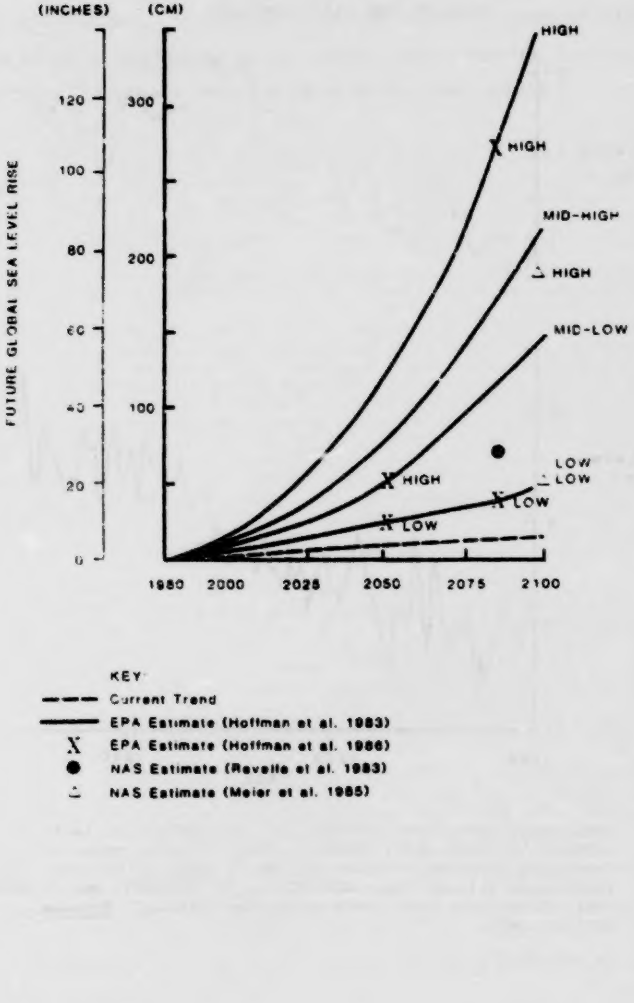
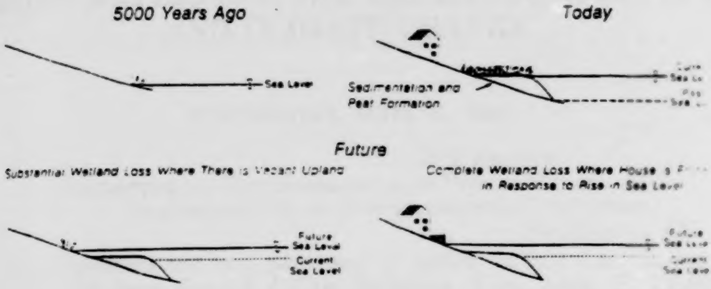


FIGURE 3

EVOLUTION OF MARSH AS SEA LEVEL RISES


5000 Years Ago
Today
Sea Level
Sedimentation and
Peat Formation
Curre
Sea Le
Pas
Sea
Future
Substantial Wetland Loss Where There is Vacant Upland
Complete Wetland Loss Where House is F
in Response to Rise in Sea Level
Future
Sea Level
Current
Sea Level
Future
Sea Leve
Current
Sea Leve

Coastal marshes have kept pace with the slow rate of sea level rise that has characterized the last several thousand years. Thus, the area of marsh has expanded over time as new lands were inundated. If in the future, sea level rises faster than the ability of the marsh to keep pace, the marsh area will contract. Construction of bulkheads to protect economic development may prevent new marsh from forming and result in a total loss of marsh in some areas.

OZONE DEPLETION, THE GREENHOUSE EFFECT, AND CLIMATE CHANGE

WEDNESDAY, JUNE 11, 1986

U.S. Senate,
Committee on Environment and Public Works,
Subcommittee on Environmental Pollution,
Washington, DC.

The subcommittee met, pursuant to notice, at 9:35 a.m., in room SD-406, Dirksen Senate Office Building, Hon. John H. Chafee (chairman of the subcommittee) presiding.

Present: Senators Chafee, Stafford, and Mitchell.

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator **Chafee**. Good morning.

This morning we are continuing the important hearings on two related problems that deal with the pollution of the Earth's fragile atmosphere. There is the problem of ozone depletion, and there is the problem of the greenhouse effect, and the climate change.

Yesterday, we had some powerful, graphic, and clearly disturbing testimony from several distinguished scientists about the nature of the problems, including the likely timing and magnitude of predicted changes and the risks posed by such changes.

I think any of you who were here certainly found it a sobering experience.

Today's hearing will focus on what is being done by the Federal Government, domestically and internationally, to improve our understanding of these problems and to respond to them.

Yesterday, I explained why we are taking the time to address these matters. We are doing so because there is a very real possibility that man, either through ignorance or indifference, or both, is irreversibly altering the ability of our atmosphere to perform basic life support functions for our planet.

As stated yesterday, this hearing must depart from previous examinations of these problems. Ozone depletion and the greenhouse effect can no longer be treated solely as important scientific questions. They must be seen as critical problems facing the nations of the world, and they are problems that demand solutions.

To set us on a path leading to solutions in the near future, I announced six initiatives that my colleagues and I will be pursuing. Some of these call upon today's witnesses to begin specific tasks, and I would be interested if they have any immediate reactions.

For example, Mr. Thomas will be testifying, and yesterday I asked the EPA to launch immediate studies setting forth policy options that, if implemented, would stabilize the levels of atmospheric gases. These studies are expected to address significant changes in energy policy, in terms of both improvement of energy efficiency and development of alternatives to fossil fuels; reductions in the use of CFC's, and ways to reduce other greenhouse gases such as methane and nitrous oxides,. as well as rates of deforestation and reforestation efforts.

The thought is not to embark on a 5- or 10-year study, but to conclude these studies in fairly short order; say, 1 or 2 years.

The EPA will be also asked to coordinate a study on the environmental effects of climate change which were set forth so graphically yesterday by the scientists.

The Department of State, which is represented here today, will be asked to bring these issues to the attention of other nations by, at a minimum, scheduling discussions of these matters at the next summit meeting with the Soviet Union, and the next international summit.

The reaction of our witnesses to the suggestion that all Federal agencies be directed to recognize ozone depletion, the greenhouse effect, and climate change as environmental impacts, and must be considered in the NEPA process, would also be of interest to members of this committee.

Yesterday, I stated that it does seem as though what man is doing to this planet of ours just continues on and on. The effects of our actions, what we produce, the burning of the fuel, the chemicals we produce, always seem to wreak havoc on this planet. But to many of these, and hopefully, I think, to most of these problems there are solutions. We have found solutions. For example, the disposal of hazardous waste, we are working on that. The disposal of the nuclear waste, we haven't yet found a solution for that, but at least people are directing their attention to it.

It seems to me that what is required for all of us is to do a better job of anticipating and responding to the warnings that are so clearly out there before us, rather than wait until the environmental tragedy is upon us. That is the task that we face today, and that we are trying to shed some light upon as a result of these hearings.

We welcome the first panel, which consists of the Honorable Lee Thomas, the Administrator of the Environmental Protection Agency; the Honorable Clarence J. (Bud) Brown, the Deputy Secretary of the Department of Commerce; Dr. William Graham, Deputy Administrator of NASA, who has been designated by the President as the Director of the White House Office of Science and Technology Policy; Dr. Graham, we welcome you here; the Honorable Richard Benedick, Deputy Assistant Secretary for Environment, Health and Natural Resources in the Department of State; and Dr. Alvin Trivelpiece who is the Director of the Office of Energy Research at the Department of Energy.

I know that Dr. Graham has a commitment in about an hour, so we will see that you will be out of here on time. Will it be satisfactory if you leave here at 10:45?

Dr. GRAHAM. Yes; thank you.

Senator **Chafee**. Why don't we start with Lee Thomas, and go in the order that you were called, bearing in mind Dr. Graham's commitment.

Mr. Thomas, why don't you proceed.

STATEMENT OF HON. LEE THOMAS, ADMINISTRATOR, ENVIRONMENTAL PROTECTION AGENCY

Mr. **Thomas**. Thank you, Mr. Chairman. I appreciate the opportunity to be with you today.

You have a copy of my testimony, I believe.

Senator **Chafee**. I will just tell all the witnesses, we will put all of the prepared testimony in the record, so don't worry about that. Also, we are going to make an attempt to restrict everybody to 5 minutes. If you go a little bit over, that is fine, but try to gear yourself for 5 minutes.

Mr. **Thomas**. Thank you, Mr. Chairman. Therefore, I will just highlight my testimony for you.

I commend you for holding these hearings. Clearly, the issue is an important issue, and one that the Environmental Protection Agency is actively involved in reviewing, and has been for a number of years. I am prepared to discuss with you the issues of the changes in the chemical and physical makeup of the Earth's atmosphere, of possible public health and environmental implications of these changes, and EPA's efforts to understand and address the concerns associated with those changes.

Based on our current understanding, we believe a small change in the amount of UVB radiation striking the Earth and/or a change in the Earth's mean temperature could have significant environmental and health consequences. Clearly, you heard that discussed in detail by eminent scientists yesterday.

The fundamental scientific and policy uncertainty is no longer, are the phenomena real, but rather the question is: At what rate are they likely to occur? What is the full nature of the impact of the changes, and what are our policy options for managing those risks?

EPA is active in participating in the review of climate change, and dealing with the issue of stratospheric ozone depletion. I would like to outline briefly what we are doing in this regard.

As you know, both issues are extremely complex, scientifically and technically. They are global in their effects, as they will be in their solutions. For these reasons, the demand for an international as well as a domestic coordination process, on the science as well as the policy, is as great as any issue we deal with.

First, turning to ozone depletion, as you know, we have a specific mandate, under the Clean Air Act, section 157, to deal with this issue. It was given to us in 1977 when the Clean Air Act was amended. There have been actions in the past, of which I am sure you are aware, since that act was amended both in 1978 and 1980 as far as U.S. domestic activity is concerned, as well as participation in the international forum.

In January of this year, we published a Federal Register notice which laid out our current process and understanding as far as the ozone depletion issue is concerned. This notice stated how we intend to deal with this issue. It was responsive to our review of the issue, and it was also responsive to litigation, and a settlement of that litigation, concerning actions of the agency.

Elements of that plan include a determination of whether additional regulations are needed domestically by November of 1987 and, if so, what they would be; the reestablishment of the Interagency Coordinating Committee on Stratospheric Ozone Depletion, which we have done; a series of assessment workshops assessing the effects and all of the implications of stratospheric ozone depletion, which also have begun; and active support for the Vienna Convention, which as you know dealt with the international aspects of ozone depletion, and resulted in a convention that is currently under review by the Senate, and which is supported by this administration. Additionally, the plan calls for active EPA participation and sponsorship of international workshops on ozone depletion. This all leads up to both international and domestic decisionmaking in the November 1987 timeframe.

On climate change, the agency also has been active in its participation. With a different mandate than the specific one under the Clean Air Act for ozone depletion, we have actively participated, particularly with other agencies, with the National Climate Program Office which has lead responsibility for scientific evaluation, and with overall coordination across agencies.

We have participated in evaluating future emission trends, non-CO_2 gases, effects work on climate change specifically related to sea-level rise, and several other issues. I have also established an Interagency Climate Change Work Group that is focusing across our agency on policy and research needs related to climate change, and both interagency and international cooperation.

This Climate Change Work Group is a work group within EPA, and it cuts across Policy, Air, and a variety of other offices, including our Research and Development Office.

In conclusion, Mr. Chairman, I would make a number of points.

First, the issues are complex. Scientific and technical uncertainties have prompted debate for a number of years. Our scientific understanding, however, seems to be improving. The trends seem to be toward confirmation of the problems. Clearly, decisions can't wait on certainty in the science; the global implications are too great, and I believe some intervention will have to be our course of action.

Controls present major technical, social, and economic problems, and I don't believe that they can be viewed as all or nothing options.

Effects work and policy analysis must increase as we look at the reduced scientific uncertainty, and particularly what the implications are for control options, as well as the effects of those controls or no controls.

The international and domestic level of understanding and debate, I believe, must be elevated now. EPA is committed to an active role, both domestically and internationally, in pursuing this issue.

Finally, in review of the recommendations or suggestions that you made in your opening statement, I generally agree with the recommendations for additional action, seeing those as complementary to the actions that we currently have underway. I feel that our review of the specific suggestions you have made for EPA will allow us to determine how well to carry those out, what the implications of carrying them out are, and how they can be integrated into our overall action plan, particularly as it relates to ozone depletion.

I appreciate the opportunity again to be with you, and I look forward to answering your questions.

Senator CHAFEE. Thank you very much, Mr. Thomas.

Mr. Brown, Deputy Secretary of Commerce.

STATEMENT OF HON. CLARENCE J. BROWN, DEPUTY SECRETARY OF COMMERCE

Mr. BROWN. Thank you, Mr. Chairman.

The Department of Commerce, that is NOAA and NBS, like the rest of the Federal Government, has had to make difficult choices over the past few years because we have tried to keep the Federal spending down. However, recognizing the importance of a coordinated effort to understand and predict climate variability and its possible impact on society, we have made every effort to provide the necessary resources for scientific research in this area.

NOAA is responsible for, first, monitoring the state of the atmosphere, including temperatures and the presence of key gases, which are known to affect the air quality and climate; second, conducting research to understand the processes that determine climate; and, third, establishing the baseline for variability from average natural climate in order to improve our ability to predict the degree and effect of climate change. NOAA's research is directed toward determining the sensitivity of climate to natural disturbances and the possible impact on global society of manmade environmental changes.

The Earth's climate; that is, the average state of the weather, responds to three factors: First, external forces, such as changes in solar activity, both short term and long term; second, internal interactions between the ocean and the atmosphere; and, third, environmental changes caused by man's activities, particularly since the industrial revolution, such as the addition of chemically and radiatively active gases in the atmosphere. We do not know which of these factors is most influential in causing observed recent changes in our global climate.

We know that biosphere reacts to the external forces, both to exacerbate and moderate them. It would now appear that the biosphere may also be reacting to manmade impacts, to moderate and exacerbate them as well.

There is a generally accepted view, based on over 25 years of data on atmospheric carbon dioxide concentrations from observations by NOAA laboratories and from our knowledge of the physics of the atmosphere, that the net effect of human activities will be to produce, over the next half century, a global warming of the lower atmosphere by about 2 to 4 degrees, with a much greater cooling of the stratosphere.

A climate change of this magnitude could have far-reaching global effects on society. For example, the global warming of the early 1900's that resulted in the Midwest Dust Bowl amounted to only about a half degree centigrade. The Dust Bowl was one example of localized and short-term changes. Other examples of local impacts include the increase in the level of the Great Salt Lake, the changes in the levels of some of the Great Lakes. While of significant local importance, they are not of global scale. However, they could be the result of some basic global change.

Projections of future climate, therefore, should be made cautiously, and should take into account two important caveats. First, while experiments project an average global warming due to increased carbon dioxide, no direct climate change due to increased carbon dioxide has been confirmed.

Other unknown external and internal factors can affect climate variability, which can be cyclical with differing frequencies of occurrence and time duration. One of the most significant events that we have had in recent years was the extreme 1982–83 El Nino, and that resulted in the United States taking a lead in initiating a major international research program known as the Tropical Ocean Global Atmosphere, TOGA, in the Pacific Ocean, which began in January 1895. NOAA continues to lead U.S. participation in this program.

Further, this century showed global warming until about 1940, and then cooling until the 1970's. Within the last 8 years, there again has been a warming of the global climate, but we do not know if that trend will continue. I am attaching a graph to the back of my testimony which indicates what has been going on since about 1850.

We have very limited understanding of the possible feedback effects in the biosphere global climate system; that is, factors that can reinforce or counteract certain influences from outside the Earth, particularly the Sun. For example, during October of every year since the late 1970's, scientists have observed an astonishing reduction, reaching last year to 40 percent, in the ozone over Antarctica.

The result of this phenomenon is that the National Oceanic and Atmospheric Administration has been playing an active role in the study of these and other questions. One of our activities will be to go with the National Science Foundation and the National Aeronautic and Space Administration, on an expedition to Antarctica to investigate the chemical hypotheses for the causes of the ozone anomalies in Antarctica.

The National Oceanic and Atmospheric Administration is playing an active role, as I said, in the studies of these and other questions relating to climate. One of NOAA's missions is to predict climate, and to predict, we must observe and understand the effect of carbon dioxide and ozone as well as other greenhouse gases on the global climate.

In carrying out this mission, NOAA provides long-term monitoring of atmospheric chemical constituents. NOAA continuously monitors greenhouse gases at four observatories located roughly from pole to pole.

In addition, in order to understand the dynamic of global climate, NOAA's scientists simulate its behavior with mathematical models. For example, at the NOAA Geophysical Fluid Dynamics

Laboratory in Princeton, NJ, a model is used to conduct various types of experiments based on past and present global climate data as well as future projections in an effort to improve our ability to predict the possible impact of increased carbon dioxide or trace gases on the climate.

The level of the sea also may be an indicator of global warning. Sea level has risen about 100 meters since the end of the last ice age, about 15,000 years ago. Until recently, interannual and longer term sea level fluctuations could not be easily distinguished from vertical land motion, subsidence or uplift, which made it difficult to estimate actual changes in mean sea level.

Recent advances in geodetic techniques now make it possible to measure exactly and discriminate between real changes of absolute sea level and apparent changes due to vertical land motion. NOAA is monitoring the sea level in addition to atmospheric gases in order to establish a baseline of natural variability.

NOAA also gathers and analyzes data on global cloudiness. Under the International Satellite Cloud Climatology Program, measurements are collected from the five geostationary meteorological satellites and the polar orbiting satellites to obtain a data set of global cloudiness in a format that is easily accessible for study. The United States, the European Space Agency, Japan, France, and Canada are involved in this program.

NOAA is also monitoring and studying the sources and causes of ozone formation and depletion and the effect of ozone change on our climate. NOAA also monitors ozone and temperature on a global scale from its operational weather satellites. Ozone is a greenhouse gas which is increasing in the lower atmosphere. It is beneficial in filtering out ultraviolet rays, and its depletion in the atmosphere could result in an increase in skin cancer and other environmental consequences. Ozone changes in the stratosphere also will vary the temperature in the stratosphere. At this point, we are not fully certain what overall impact changes in atmospheric ozone would have on global climate, but we are in the process of trying to make the determination.

The National Bureau of Standards, in addition to NOAA's programs, has developed standard reference materials for calibrating instruments that measure the concentration of important gases such as carbon dioxide, ozone, methane, and some freons in the air.

Within the Federal Government there is considerable excitement about pushing forward with research to monitor, understand, and predict climate changes due to various greenhouse gases and the possible changes in stratospheric ozone. The National Climate Program Act of 1978 established a mechanism for interagency coordination within the Federal Government. The National Climate Program Office within NOAA acts as the secretariat for the coordination of agency activities with the guidance of the National Climate Program Policy Board. The NCPO coordinates the interagency planning activities of 17 Federal agencies, including the Department of Energy, the Environmental Protection Agency, and NASA, to name a few, in order to avoid duplication of effort and ensure that key problems are addressed.

We are continuing to realize that our planetary life support system is dynamic, and that it depends on a wide variety of natural balances which can be significantly affected by man's activities. As the global population and technological changes increase and become more complex and interdependent, it is critical that we understand how natural climate variability and the impact of man's activities on the climatic system affect our health and environment.

Senator **Chafee**. Thank you very much, Mr. Brown.

Now we will hear from Dr. Graham.

STATEMENT OF WILLIAM GRAHAM, DEPUTY ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. **Graham**. Thank you, Mr. Chairman.

I am pleased to be here today to discuss the current research activities and the role of the National Aeronautics and Space Administration with respect to the issues of ozone modification and climate changes.

I have prepared a written statement which, with your permission, I will summarize.

NASA has major elements of its program which address the ozone and climate issues. We recognize that these issues are strongly coupled because the trace species that cause changes in ozone are the same gases that are predicted to produce climate warming.

NASA's satellite remote sensing systems' computational and modeling capabilities make it uniquely suited to study these two global concerns.

At the direction of Congress, NASA implemented the Upper Atmosphere Research Program to provide for research, technology development, and monitoring of the Earth's upper atmosphere, with particular emphasis on the stratosphere.

A summary of NASA's research activities was provided to Congress in January, and were summarized by Dr. Watson from NASA yesterday. Our knowledge of the processes controlling the stratosphere have advanced greatly in the last few years, but uncertainties still remain and need to be resolved by a vigorous program of continued research.

NASA is committed to continuing its leadership role in studying atmospheric chemistry and in working closely with the scientific community, and U.S. and international agencies to that end.

Key components of the Upper Atmosphere Research Program, in the near term, include continuation of theoretical modeling and laboratory research; a vigorous effort to understand the processes responsible for the recent decrease in the ozone column above Antarctica determined recently by satellite measurements, as I am sure you are aware, Mr. Chairman; design and implementation of a ground-based system for early detection of ozone changes, and the continued effort to measure stratospheric composition on balloon, rocket, and aircraft platforms; and the upper atmosphere research satellite, which will provide the first simultaneous global measurement of trace species, winds, and solar inputs.

In the longer term, NASA plans to incorporate a set of stratospheric measurements as a part of the proposed space station polar platform, the Earth observing system. The most important recent development in our knowledge of stratospheric chemistry has been the analysis of data of the Nimbus satellites and the ATMOS instrument flown on Space Lab III.

The NASA Climate Research Program was reoriented in response to the National Climate Program Act to improve our understanding of the radiation and dynamical processes which govern the Earth's climate system, and to observe the physical properties which influence its change.

A fundamental goal of the NASA program is to understand the basic nature of solar and emitted Earth radiations. The broad nature of this research has required close coordination with other Federal agencies, and with the international scientific community through the World Climate Research Program.

Recent data have been obtained from the NASA-built Nimbus VI and VII satellites, the Solar Maximum Mission, and the Earth radiation budget experiment satellites.

The study of the role of clouds and climate has been given a particular emphasis in the NASA program, including the development of a climatology of important cloud parameters over diurnal, seasonal, and interannual periods, and the development of models for the basic physical processes involved.

Crucial measurements for understanding the role of oceans include ocean circulation, sea surface winds and temperatures, biological productivity, and polar ice cover. A scatterometer, to measure winds on the ocean surface, is under development for the Navy remote ocean sensing satellite, and the ocean/space topography experiment, TOPEX, which will be used to determine the detailed topographical structure of the ocean surface has been submitted as a new start for our 1987 budget.

NASA plans to continue these measurements, along with an ocean color measurement and the NOAA operational instruments on the space station polar platform.

NASA is supporting the development of the international land surface climatology project to provide quantitative information from satellites. Such monitoring will identify man's direct influence through agricultural practices and deforestation, and observe changes on land surface as a result of changes in the climate itself.

The ozone and greenhouse warming issues, which have been discussed during these hearings, are just two of the environmental issues we face today. To gain an understanding of how human activities will affect the Earth's environment requires a new approach to the Earth sciences. We need to obtain a scientific understanding of the entire Earth system on a global scale, by describing how its component parts and their interactions have evolved, how they function today, and how they may be expected to continue to change on all time scales.

The immediate challenge is to develop the capability to predict these changes that will occur over the next decade to the next century, those changes being caused by both the natural effects and in response to human activity. This will require a nationally and internationally coordinated program of interdisciplinary research to investigate the long term, that is, the 10 to 100 years, physical, chemical, and biological changes in the Earth's environment, recognizing that many land atmospheric, oceanic, and biospheric processes are strongly coupled on a variety of temporal and spacial scales.

Such a research program is necessary for informed policy decisions. The National Academy of Sciences, the National Research Council, and the International Council of Scientific Unions are currently formulating such a research program, known as the Global Change Program, which will build upon many of the ongoing national and international research programs in the Earth sciences.

NASA has initiated an interdisciplinary research program, and NASA is ready to cooperate with the proposed national and international program, in conjunction with the scientific community, and with NOAA, the Department of Commerce, the National Science Foundation, the Department of Energy, the State Department, the Environmental Protection Agency, and other governmental agencies.

The Earth System Sciences Committee was established in 1983 by the NASA Advisory Council to develop a near-term program and to recommend a specific NASA role in the Earth system sciences. The report of that committee will be released in the near future, and will be forwarded to you.

Senator CHAFEE. Thank you very much, Dr. Graham.

Mr. Benedick.

STATEMENT OF HON. RICHARD BENEDICK, DEPUTY ASSISTANT SECRETARY FOR ENVIRONMENT, HEALTH AND NATURAL RESOURCES, DEPARTMENT OF STATE

Mr. BENEDICK. Thank you, Mr. Chairman.

I am delighted, on behalf of the Department of State, to participate in this important hearing.

Mr. Chairman, it is increasingly clear that protecting the environment is an issue that transcends national boundaries. Indeed, such problems as global climate change and ozone modification, because of their very nature, require coordinated international approaches both in research and in policies.

Environmental matters have, Mr. Chairman, become in recent years important additions to the U.S. foreign policy agenda. The State Department represents the United States at governing bodies of the United Nations Environment Program, the Organization for Economic Cooperation and Development, the Economic Commission for Europe, and other multilateral fora dealing with the environment.

The State Department also leads U.S. delegations at international negotiations, including those dealing with protecting the ozone layer, with transboundary air pollution, and with protection of oceans and regional seas.

Mr. Chairman, in March 1985, I represented the United States at a plenipotentiary in Vienna, where 21 nations signed the Convention for the Protection of the Ozone Layer. This was a plenipotentiary where 21 nations signed a convention for the protection of the ozone layer. This was a landmark event.

This was the first time that the international community acted in concert on an environmental issue before there was substantial damage to the environment and health. In effect, countries acted together in anticipation of potential problems. This convention, which creates the frame work for international cooperation on research, monitoring, and exchanging information, is currently before the Senate for ratification.

Significantly, it has the support of both industry and environmental groups, who share an interest in development of better data on what is happening to the ozone layer.

Senator CHAFEE. Any time that there is an agreement that nobody objects to, I get very nervous. Is it such Pablum that it doesn't choke anybody? Tell me a little bit about it?

Mr. BENEDICK. Mr. Chairman, I believe that the explanation for this is that both the environmental groups and the industry want to see the decisions made on the basis of accurate scientific data, the best data possible, rather than perhaps overreactions based on emotion or exaggeration. That, I think, is why they are supporting this particular convention.

Such issues as global climate change, and the ozone layer, are certainly complex and sensitive. They are often at the frontier of several interrelated scientific disciplines, and they are based on projections that extend many decades into the future. Human health, jobs, agriculture, international trade, and investment are all involved. Policymakers may be called on to act even while there is still scientific uncertainty over the causes or the extent of potential threats to environment and health.

For these reasons, Mr. Chairman, we believe that scientific and economic research is an essential prerequisite and accompaniment to international negotiation. Research to assess the risk, to narrow the range of uncertainties, and to estimate the costs of different policy options.

I am personally convinced that in dealing with such issues, where so much is at stake, it is ultimately more efficient to avoid exaggeration or overreaction. Instead we must work to prudently develop a scientifically based rationale for the broad, domestic, and international consensus that is needed before policy actions can be taken.

Considering the tempo of international activity on global warming, and on ozone layer modification, the multifaceted international meetings and research efforts detailed in my prepared testimony, and that of the others on this panel, I believe that this process is well advanced.

I want to emphasize that we take these issues seriously. The U.S. Government is engaged and is, indeed, at the forefront of these international activities.

Thank you, Mr. Chairman.

Senator CHAFEE. Thaok you, Mr. Benedick.

Dr. Trivelpiece.

STATEMENT OF ALVIN TRIVELPIECE, DIRECTOR, OFFICE OF ENERGY RESEARCH, DEPARTMENT OF ENERGY

Dr. TRIVELPIECE. Thank you, Mr. Chairman, for the opportunity to be here this morning and talk about some of the activities that DOE is involved in.

Previous individuals here on the panel with me have mentioned the National Climate Program Act. That act contains several thrusts. One of those thrusts involves CO_2, and since one of the principal sources of CO_2 in the atmosphere is fossil fuels, the Department of Energy was given the lead responsibility for coordinating this activity.

Of the approximate $23 million the United States spends on this activity each year, the DOE's research activities account for over one-half of that. Other agencies account for the rest.

Also, as Mr. Thomas mentioned, this is a very complex problem, and it is a problem of sources, and a problem of sinks. It is a problem of causes and effects, and it is also a problem of knowledge and ignorance.

So the question is: What about the knowledge aspects of this? The Department of Energy has, over the last 3 years, coordinated the preparation of studies, which are called state-of-the-art reports, and these reports deal with various things. One of them is detecting the climate changes that may be due to CO_2, and the other is projecting what these effects might be. The other is the atmospheric aspects of the carbon cycle and the global aspects of it. Finally, the direct effects of increasing carbon dioxide on vegetation and what can be done.

These four reports tell us a great deal, and they serve as some guide for the future activities that we may be required to carry out. I think that one of the findings of them is, it is clear that there is, based on the information available, a likely increase in the temperature over the next 100 years. People here have quoted various numbers. There is still some uncertainty in this, but I don't think the trend is at issue.

You have cited the aspect of international character of this, and I think that it is important to keep this in mind. For instance, in 1950, the concentration was about 310 parts per million, and in 1980, 330 parts per million. North America, in 1950, contributed 43 percent of that, and today it is about 27 percent. For the Europeans, it has gone from something around 30 percent down to 24 percent. On the other hand, in that same period, what has happened is that there has been an increase in Eastern Europe from 18 to 24 percent, and in the underdeveloped countries, it has gone from 6 to 12 percent.

Senator **Chafee**. Those declining percentages don't mean that the tonnage emitted was less. They just have a smaller piece of a bigger pie.

Dr. **Trivelpiece**. My point is that they are becoming an increasingly important phenomenon.

Senator **Chafee**. You mean the Third World nations.

Dr. **Trivelpiece**. Yes; and we could do a great deal here in the United States to control things within the United States, and it would have very little effect on the global amount of carbon dioxide delivered in the atmosphere.

Senator **Chafee**. I wouldn't say, "a little effect." Even under the increased amounts coming from Third World countries, the United States is still what percent; did you say 24?

Dr. **Trivelpiece**. Yes.

The point is also that from 1950 to 1980, the amount of metric tons per person per year has grown, from U.S. carbon, from about 4 to 4.4, which is 10 percent, whereas some of the other undeveloped countries, it has grown by factors of 300 percent which, even though the amount is not very much, the trend is what it is that is of concern at the moment.

These trends clearly identify the fact that this is an international problem, and I think that some of your emphasis in your remarks that this is something that has to be done on an international basis is clearly right on the mark. We must try to identify where the sources and sinks are, and what we can do about them.

The state-of-the-art reports that we prepare, I think, serve as a guideline to indicate what we know, what we don't know, as well as things that are uncertain and things that can be done.

One of the final things that I would like to mention is that there are causes and effects, most of which are clearly detrimental. On the other hand, it is clear that vegetation does grow better with increased CO_2, and there are certain crops whose yield increases from 30 to 80 percent, or would increase by that amount based on doubling of the CO_2 in the atmosphere, but I don't think that this is something that we should plan on, but rather to try to take advantage of what we know about it to perform appropriate mitigations.

Mr. Chairman, I think this covers what I wanted to say. Thank you.

Senator CHAFEE. Thank you, Dr. Trivelpiece.

We are delighted that the chairman of the full committee is here.

Senator Stafford, if you have a statement, it would be appropriate at this time.

Senator STAFFORD. Thank you very much, Mr. Chairman. I don't have a statement. I may have one or two questions when the time comes. I find this a very interesting subject, and I am glad that we are pursuing it. I am also glad that you are spearheading our pursuit.

Senator CHAFEE. I know how busy you are, so we appreciate your coming by.

Senator Mitchell, the ranking member of the subcommittee, we welcome you. If you have a statement, this would be the appropriate time.

Senator MITCHELL. No, Senator; thank you. I made a statement yesterday, and I will repeat only that portion of it in which I commended you for holding these hearings to call attention to what is clearly a grave problem confronting the Nation. I look forward to working with you in developing a policy to deal with the problem.

I do have a series of questions for the witnesses at the appropriate time.

Senator CHAFEE. Thank you very much.

Since Dr. Graham has a deadline, I thought that I would ask some questions of him and then perhaps, Senator Stafford, if you have any, and Senator Mitchell. Then we could excuse Dr. Graham, and proceed with the other witnesses.

Dr. Graham, I know that you are taking on other responsibilities very shortly as the Science Adviser to the President. When do you assume those duties?

Dr. **Graham**. Mr. Chairman, that is at the will of the Senate. That position requires confirmation, and I anticipate that it will go before the Senate within the next 2 months.

Senator **Chafee**. I certainly hope so. I suspect that you are going to be confirmed.

Dr. **Graham**. Thank you, Senator.

Senator **Chafee**. What I am interested in is what are you going to say to the President about the problems of ozone depletion, greenhouse effect, and climate change?

Suppose he calls you in and says: Dr. Graham, I am interested in this, and should we do something now, or do we need more scientific evidence?

Senator **Stafford**. Mr. Chairman, after Dr. Graham has spoken to the President, I would be even more interested to know what the President might say in reply.

Senator **Chafee**. Let's get what he is going to say first; let's do it one step at a time. What are you going to say, Dr. Graham?

Dr. **Graham**. Senator, I wouldn't presume to get ahead of the confirmation process and try to speak as the Science Adviser to the President at this point. However, as the Deputy Administrator of NASA, I can certainly give you my views on that position.

Senator **Chafee**. Either way.

Dr. **Graham**. The issue of both trace gas and changes in the atmosphere, and their effect on the ultraviolet incidence on the surface of the Earth, and their effect on the climate, and climatic structure of the Earth, are both potentially very significant. The time scale of these activities, of these changes seems to be such that it doesn't drive one off a cliff from one day to the next, and in that way it makes the problem in some sense more insidious, because it comes along a step at a time.

In the first instance, we are very fortunate to be in an era when we can monitor these effects, these changes, these concentrations on a global scale because I believe that it is now clear that we have a problem of coupled global systems which interact in some instances very strongly and, therefore, have to be monitored both from a diversity of manifestation, but also across a global scale, and across time domains that are measured in years, and potentially decades. That monitoring can be conducted through a number of instruments and a number of sensors, some of which are fixed Earth instruments, and at the other end of the spectrum go to satellite bases, the space station, and the platforms associated with that.

The President, of course, has been a very strong supporter of the National Space Program, and has mandated that we proceed with the space station, which will include man-tended platforms in a polar orbit within the next decade. We are working to that schedule.

Senator **Chafee**. That is fine, and I am all for that, but should we do anything now?

My question to you, Dr. Graham, is what do we do now; more studies, or do we try to tackle the CFC matter, for example?

Dr. **Graham**. We certainly must continue a program of monitoring, both the elements that we think are causing the change and the change itself. We also have to continue a very vigorous program of research to make sure that we identify what is significant, both in terms of the contaminants in the atmosphere, the trace elements, and their change.

Beyond that, it comes to a regulatory question, Mr. Chairman. While in possible future lives, I may have an involvement in the regulatory policy, I can also state that NASA itself does not act as a regulatory agency, and would turn to my colleagues at the table for specific regulatory advice at this point.

Senator **Chafee**. Yesterday, we had a very distinguished panel consisting of Dr. Watson, Dr. Rowland, and Dr. Hansen; Dr. Watson being a colleague of yours at NASA, and they sounded an alarm. They said that, indeed, the Earth is heating up, and that there is a cause and effect, the carbon dioxide, CFC, a series of matters, and we had better do something about that.

They went much further. They were all for more studies, but they said that we ought to do something. What do you say to that?

Dr. **Graham**. I have been quite concerned with that problem for years, and, in fact, the company that I helped found did research in that area, among others, Mr. Chairman. It is a matter of considerable concern to me, and it is clear that, should specific action beyond that which the United States has already taken in the control of fluorocarbon emissions be warranted, that that should be given the most serious consideration.

Senator **Chafee**. You are kind of hedging your statement, Dr. Graham. If some action should be taken, we should take some action, seems to be what you are saying. Do you think that we should take some action? That is my question.

Dr. **Graham**. Mr. Chairman, I would be more comfortable with taking additional specific action when I found the basis of our understanding for what is going on now to be more sound. That is why I suggested, in the first instance, that we must continue a vigorous research program, but we must also continue a vigorous monitoring program.

As you may know, right now, our analytical models of the ozone concentration, for example, misestimate the ozone concentration on the order of 50 percent. The study of the feedback in the climate through such things as cloud cover, and cloud generation, can have a very strong effect on that climate, and yet we can't model that accurately at this point.

There is no question that we are moving toward a warming trend. I think that has been well established, and that is a matter of considerable concern, and we have to know the full implications of that to the climate. I am not prepared today to state what specific action should be taken to accommodate that, but there is no question that if the present research is borne out by continued observation, and continued scientific exploration, that we should consider taking further action.

Senator **Chafee**. Your colleague showed a film yesterday of the ozone hole appearing in the month of October over the Antarctic, and I am sure you have seen that. I don't know what it means, but something is happening that is pretty significant.

Dr. **Graham**. That is certainly the case, Mr. Chairman. Furthermore, the scientific community today does not understand or at least does not have a consensus in understanding what is creating that factor of two reduction in the ozone concentration in certain seasons over the Antarctic. That is one of the issues that we must pursue in the short term to understand, and that is exactly the kind of observation and monitoring that we need to pursue vigorously to make sure we know what is going on in the climate and in the environment of the Earth.

Senator **Chafee**. Senator Stafford, do you have any questions of Dr. Graham?

Senator **Stafford**. I do have a few, Mr. Chairman, thank you.

First, Dr. Graham, yesterday, we got the understanding that ozone in the lower atmosphere is bad, where we are generating quite a lot of it, but in the upper atmosphere, it is good because it shields us from ultraviolet light.

My first question is: Has there been any scientific research to determine whether or not there has been a serious depletion of ozone in the upper atmosphere in areas other than that over Antarctica?

Dr. **Graham**. Senator Stafford, I believe that that has been monitored in other regions, the North Polar region, and to some extent, the midlatitude zone. I believe that the strongest changes that have been observed to date are those which have been described over the Antarctic region.

Senator **Stafford**. Let me understand you fully. There have been, however, some incidents of depletion elsewhere, as I understand you to say?

Dr. **Graham**. There is always a question in these experiments in monitoring efforts to determine how much of what you are seeing is seasonal variation, or variation on longer scale, but not systematic long-term variation, and how much is, in fact, long-term systematic variation.

I would be pleased to provide you with more information, Senator.

Senator **Stafford**. Thank you.

Has the loss of any of our satellites due to errors, or unfortunate events in launching them, hampered our upper atmosphere research at all?

Dr. **Graham**. The present situation of the United States, in fact, the entire Western Alliance is today one of being substantially unable to place scientific and other satellites into orbit. That situation will continue for the United States for at least the next year as it relates to the space transportation system, the space shuttle, and I hope a shorter period of time as it relates to the expendable launch vehicles, the normal rockets, which we already have in the inventory.

Nevertheless, in my view, it is inevitable that there will be some decrease in our capability to monitor the Earth and the Earth's environment over the next few years compared to where we would have liked to have taken that capability because of both the *Challenger* accident, and because of the expendable launch vehicle failures that the Air Force and NASA have experienced over the short term.

Senator **Stafford**. Mr. Brown.

Mr. **Brown**. What we have in the air, however, in weather satellite currently is still continuing to produce information on that subject, Mr. Senator.

Dr. **Graham**. I might add to that, Senator Stafford, that we have some 21 scientific satellites still operational in space, and will continue to receive data from those. So while we are not going to make progress as fast as we had hoped with our plans before this series of unprecedented accidents, nevertheless there will be very substantial data return from space over the next several years.

Senator **Stafford**. Thank you.

Now, let me be the devil's advocate here for just a minute because one of the witnesses this morning testified that between 1940 and 1970 the globe was in a cooling trend, and that had to have been during a period of very high use of both coal and other fossil fuels, and that from 1970 to the present there is undoubtedly a warming trend, which may also be the result of greenhouse effect.

My question is: Could some other factor have influenced the cooling trend from 1940 to 1970, and could it have been the Sun, for example, or would you have any comment on that?

Dr. **Graham**. Yes; Senator Stafford. I think this illustrates the fact that we don't fully understand the mechanisms that drive the climate of the Earth or the interaction of a number of the phenomena that we observe today on the climate and on other parts of the environment.

We now have a satellite flying which monitors the Earth's radiation budget, and it is to determine the answer to your question today, whether in fact variations in solar output or in other phenomena external to the Earth itself may have a major role in the heating and cooling of the Earth.

I think you illustrate very well the need for a continued research and monitoring program so that, in fact, we do understand what is going on. While we think that we know the trends today, we do not understand all the mechanisms, and I believe that there is not a consensus on the cause of the cooling trend that you described.

Senator **Stafford**. This final question is hardly a fair one, but I am going to ask it anyway. Could you give us your guess as to how many years of research we need to have a much more thorough understanding of the impact of human activities on global heating and cooling than we have at the present time?

Dr. **Graham**. Senator Stafford, I think that we are making very, very strong progress now, and making it on a literally year-by-year basis. I think that progress will continue for at least the next decade, and perhaps beyond that. It is a business where, when you understand the answer to one question, you also identify two more questions that you need to understand the answers to.

While our understanding today is much better than it was a decade ago, and we know significant effects that we didn't fully anticipate a decade ago, we have to continue that research program.

Senator **Stafford**. I gather that it will be several years before scientists will feel they really understand what is going on and can pinpoint what ought to be done about it. Is that a fair statement?

Dr. **Graham**. I believe that it will be several years before we have a comprehensive understanding of the global climate, and that could even be measured in the decades. I think that our understanding of ozone may come more quickly, although it has defied a complete modeling to this point.

Nevertheless, even without a final model, and understanding of all the effects that drive the climate, there are, in fact, observations, experiments, and analyses that can be done that will give us strong guidance as to how to proceed in the near term.

Senator **Stafford**. Thank you very much.

Senator **Chafee**. Senator Mitchell, I know that you have a subsequent engagement. Why don't you proceed to ask Dr. Graham your questions. He has about 12 minutes left here. Then, if you want to continue and ask the full panel questions, you go right ahead.

Senator **Mitchell**. Thank you very much, Mr. Chairman, for your courtesy, and Senator Stafford as well.

Let me precede my questioning by saying that we are again confronted with the dismaying prospect of an administration policy in the area of the environment based upon the principle that everything must be known before anything can be done. It is a familiar pattern, one which the members of this committee have repeatedly been exposed to in many areas dealing with environmental policy.

I would like to ask a series of questions which actually are applicable to each of the members of the panel, and perhaps, Dr. Graham, you could respond to them first, and then the other members could follow.

First, Dr. Graham, do you dispute the fact that there are serious adverse environmental effects of ozone depletions and emissions of greenhouse gases?

Dr. **Graham**. Senator Mitchell, I would certainly agree that there are potential adverse environmental effects of both of those phenomena. The effects to date are still under study, however, and I would think that it would be premature to make a statement concerning the state today of those.

However, the projection for the future is in fact quite serious in both of those regards.

Senator **Mitchell**. Do you have any reason to believe that the projections for the future, based upon occurrences to date, are inaccurate or unjustified?

Dr. **Graham**. I have reason to believe that projections into the future have a large uncertainty associated with them, and that uncertainty needs to be reduced as we go forward to look to specific actions in the future.

Senator **Mitchell**. In view of the magnitude of the potential adverse effects as described before this committee yesterday, it would not be an exaggeration, for example, to say that we risk virtual destruction of life on this planet. Do you not believe that prudent policy would dictate resolving uncertainties in favor of taking preventive steps now rather than waiting a decade or more, as you suggested, at which time the current projections may be confirmed, but also at which time the damage, or potential damage, would be far greater?

Dr. **Graham**. Senator Mitchell, I believe policy should be considered at this time with a view toward taking action in a timely way on each of these issues. These issues tend to have a series of time scales, depending on the specific trace gas, or effect that you are describing, and the specific effect of it. The policy should be kept in accord with those time scales, some of which, like the reduction in fluorocarbon emissions in the United States, have already been done, others of which will be a much longer time scale and would allow us the opportunity to better understand them before specific policies must be implemented.

Senator **Mitchell**. Do you dispute the fact that, at least in part, the changes to which I referred—ozone depletion and emissions of greenhouse gases—are due to human activities and, therefore, are subject to human control?

Dr. **Graham**. Every indication of research to date, Senator Mitchell, indicate that human activity can have an effect on those, and to some extent may have had an effect already, although the total effect is not yet understood.

Senator **Mitchell**. Are you familiar with the six points proposed by Senator Chafee yesterday in his opening remarks, a prudent, reasonable, modest approach based on current understanding of the problem and, if so, do you support immediate implementation of those steps?

Dr. **Graham**. I saw those for the first time this morning, Senator Mitchell, and I have not had a chance to study those carefully and give them the consideration that they deserve. I will certainly be more than pleased to do that from the perspective of the National Aeronautics and Space Administration, and provide you with a response.

Senator **Mitchell**. Has your agency, or to your knowledge, any other Federal agency made any estimate of the cost of controlling air pollutants implicated in ozone depletion, or greenhouse gases?

Dr. **Graham**. I don't believe that the National Aeronautics and Space Administration has made that estimate, Senator Mitchell, and I am not aware of it from other agencies, but they may have made such estimates.

Senator **Mitchell**. Has your agency made any estimate of the cost of not controlling these air pollutants?

Dr. **Graham**. I believe not, Senator Mitchell.

Senator **Mitchell**. Has your agency held any discussions on the need to do anything more than to further study the problem of climate changes, and the subjects under discussion?

Dr. **Graham**. Senator Mitchell, as you know, both in the mandate of the Congress, and in strong accord with NASA's own views, NASA is not a regulatory agency, nor does it wish to become one. So we defer to our colleagues in other parts of the Government for regulatory action.

However, in the scientific, the technical, and the monitoring fields, which include projections of the effects of human activities as well as natural activities on the environment of the Earth, NASA has been and will remain quite active in working with other parts of the Government, and with international organizations as well.

Senator **Mitchell**. Dr. Graham, I know that you have to go, and I thank you for your responses. If we could have the other members of the panel respond, perhaps, in a single narrative response to the series of questions which I have asked, if you can remember them all, if not, I will be glad to repeat them. I think that you get the gist of my point, though. Mr. Thomas has gone through this many times before, and perhaps he could begin, since I think it is his agency that is the most implicated in this area.

Senator CHAFEE. First, we want to thank you for coming, Dr. Graham, and wish you well in your new undertakings.

Dr. GRAHAM. Thank you very much, Mr. Chairman.

Senator MITCHELL. Good luck, Dr. Graham.

Dr. GRAHAM. Senator Mitchell, I thank you very much.

Senator MITCHELL. We hope that you are going to be a vigorous advocate for doing something about this problem, and others.

Dr. GRAHAM. Thank you.

Mr. THOMAS. Senator, first I will say, I certainly don't agree with your characterization of the administration's policy. You and I have discussed that before. Your characterization that we think everything must be known before anything can be done is just not accurate.

I am the guy who has to make the regulatory decisions and frankly, I make most of them, if not all of them, where everything is not known.

On this one, I addressed the issue directly in my opening comments and said directly that I think that we have to take action in this case with a good bit of scientific uncertainty remaining.

I am in the midst of a regulatory process, both domestically and internationally. Over the next 18 months I have to make decisions as to whether additional regulations are necessary over and above those we have in place domestically and, if so, what those may be. I also will participate actively in the international process we have underway that Mr. Benedick noted.

I think that we need considerable amounts of additional information, particularly on the broad range of control options that may be available, and we are gathering it. I gave some focus to the ozone depletion issue because of the specific responsibility we have there, but I also think that the same applies when we look at greenhouse effect, climate change, and warming trends; we are trying to take and develop a broader range of what the alternatives may be as far as controls are concerned; regulatory controls, as well as other changes that may be possible.

We have to put those in the context of international action, as well as domestic action. I don't necessarily think that domestic and international action are connected in the decisions I have to make, but clearly, practically, they are connected if we are going to come to grips with these issues.

I am dealing directly with the questions you asked, and I am dealing with them in the context of the responsibility I have as the Administrator of EPA. Over the next 18 months, I have got to make those decisions, and I know well that I am going to make them with a considerable amount of uncertainty in the areas of science as well as policy, as well as technical, impact and effects.

Senator MITCHELL. Mr. Thomas, may I interrupt you.

It is always rude when a Senator has to leave during a hearing, but it is especially rude when he has to leave before witnesses get a chance to answer his questions, but that is the uncomfortable position I find myself in. I am involved in a discussion on the floor, and I have to go to participate in that.

I apologize in advance to the other witnesses, but I will very carefully review the record.

I thank you, Mr. Chairman, for your courtesy.

Senator CHAFEE. I thank you, Senator Mitchell, and I appreciate your interest in this whole area.

Gentlemen, I will ask the same question of each of you, and I will start with Mr. Thomas.

Mr. Thomas, and all of you, we all agree there is a tremendous problem out there. We all agree that the Earth is warming up. We all agree that the ultimate consequences of this continuing at the present rate are nothing short of disastrous for the human race, and every other living species on the globe—changes in climate, changes in rainfall, changes in ocean current—just extraordinary and disastrous.

It seems to me that we know something. We know that CFC's contribute to the destruction of the ozone layer, and we have done something about that; a modest amount, but something.

My question to you is: Why don't we take the next step and ban the use of CFC's for refrigerators and for automobile air-conditioners. Yesterday, we had testimony that to change the CFC that is actually used in an automobile air-conditioner to another type that is not destructive might cost $5 out of the very substantial cost of an air-conditioner for an automobile.

My question to you is: Why don't we go ahead and at least take that little step for all kinds of refrigeration in the United States, and all imports, so that the imports are not going to get any advantage over us, giving them a time schedule in advance, by the year 1988 or 1989, or whatever we choose, recognizing that the market forces will bring that price right down, whatever the price differential is.

There is a little teeny step, and it may not be a major factor, not like banning the burning of all coal in the world, but it is something. Why don't we do that? What do you say to that, Mr. Thomas?

Mr. THOMAS. Senator, that is exactly one of the issues that I am looking at. I think your point about teeny steps, or small steps, or large steps, is a good one whether we're looking at just CFC's, or at all trace gases. We are currently trying to break out what are the various control options available both domestically and internationally. In a number of those cases, they are absolutely not easy steps to take. As a matter of fact, there are not alternatives in some cases. Decisions have major implications socially and economically in some cases, and they do have major international implications if we only do it domestically in many of the cases.

That is exactly the process, and looking at that as an example, it is exactly what I have underway now.

Senator CHAFEE. What do you say to that, Secretary Brown?

Mr. BROWN. Mr. Chairman, we generally support the thrust of the Vienna Convention, and I would remind you that that also calls for the research in this area. We are supporting that effort.

In the NOAA part of the Department of Commerce, we suspect that CFC's may be more significant than carbon dioxide. They have een around less time, and there are certainly less of them in the atmosphere. We think that they may have more significance for future environments than carbon dioxide.

However, I have to point out that the Vienna Convention has called for a cap on production of CFC's based on the fact that the United States has already reduced its production of CFC's by 30 to 35 percent back in the 1970's, ignoring that, so in effect, it looks like, perhaps, there is a trade implication in the European approach to this that says, let's have the United States reduce more than anybody else, so that we won't have to.

It seems to me that the better approach would be to limit the usage of CFC's altogether, but to do it as an international agreement, not as a unitary determination by the United States.

Senator CHAFEE. That is fine; we won't argue with that, but how do you get them to do it?

If everybody stands around and waits for the millenium to come, we won't get to first base. I don't understand the competitive problem. What is the competitive problem? You are in international trade, you are involved, you and your Department, what are the international trade aspects of this if we require every Japanese car that comes in with an air-conditioner on it has to observe this, they can't use the type of CFC that is most destructive, and obviously our automobiles would be likewise. Where do we lose our trade?

Mr. BROWN. What I am suggesting is that the proposal the EC has made is based on the fact that we have already made a substantial reduction in the United States, and we would like to see that reduction taken into account in the consideration of whatever the international proposal is, because it puts us at a considerable disadvantage in the United States since we are the major producer. But the utilization of them; that is, the emission of them into the atmosphere is broad scale now around the world.

What they are proposing is that we reduce our production, we have already reduced our production, and that they be allowed to reduce their production from a higher base. We think that it is a little unfair. We support the position of trying to get a reduction in usage.

Senator CHAFEE. Mr. Benedick, what have you got to say about that?

Mr. BENEDICK. Yes; Mr. Chairman, in 1985, the United States did support an international protocol to control CFC's, a protocol that would reflect our own internal regulations; namely, a complete ban on the use of CFC's as a propellant for aerosols. We represented that position in international negotiations.

For their part, the European Community countries also favored international accord, a protocol, but on their terms, to reflect their own internal regulations, which consisted of the production capacity cap just referred to, and a smaller limit on aerosol use.

We tried to negotiate this out. Other countries that were present, including the Soviet Union and Japan, saw no need for any protocol to control production or use at all. The Third World countries, which are also important because they have presently very low per capita use or production of CFC's, and potentially much greater, Third World countries showed no interest in the issue.

We learned from this experience, Mr. Chairman, that even with a sense of urgency, that reaching international agreements on a complex scientific issue is easier said than done, and it requires a substantial degree of international consensus on the facts.

After the Vienna Convention in March of last year, the countries that were negotiating decided to sit back, not inaction, but to take a very careful look, to try to establish a common data base to really understand what was happening, the extent and effects of ozone layer modification—these are the scientific studies that have been referred to—and also to undertake a series of workshops on projections of international supply and demand of CFC's, on the effectiveness of existing controls, and on the possible effectiveness and costs of potential new control options.

This factfinding process, as Mr. Thomas indicated, is still underway, both domestically and internationally. There is a lot of activity going on, and we trust that it will lead us to a reasonable and defensible position that is consistent with political and economic realities, and that also reflects U.S. public opinion as developed and reflected in this Congress.

Senator **Chafee**. Dr. Trivelpiece, what have you got to say?

Dr. **Trivelpiece**. I would support what my colleagues have said here. I would add that whenever you seek to persuade someone to your point of view, having available to you a set of unassailable facts quite frequently improves your position in doing so.

In this particular case, the facts still seem to be somewhat in dispute in the international arena, and to that extent the improvement of the knowledge base regarding the cause and effects here would make our position such that we would be in a better position to persuade those in the Third World, and the other developing countries, as well as our more developed country colleagues.

I think that it is important that the information be absolutely mutually agreed to, and then seek to get the appropriate type of international agreement. To do so for purely symbolic reasons here in the United States, and not have that make a major cause-and-effect change in the amount of ozone being modified, I think would be premature.

Senator **Chafee**. I have a little trouble following that rationale. It seems to me that here in the United States, we, traditionally, have tried to take the lead in world environmental matters. We are a great big country, a rich country, and a country that can take leadership. It seems to me that if we sit around and say, well, we ought to do it, but we don't want to move until everybody else is ready to move, and those Chinese and Russians, they won't do anything, on that basis, we won't get to first base.

You can get all the scientific knowledge, but I don't think there is any dispute here. Is there any dispute that emissions of certain CFC's into the atmosphere is bad; is depleting the ozone layer? Does anybody dispute that?

What about you, Mr. Brown?

Mr. **Brown**. I said, Mr. Chairman, that we think that it may be more serious than carbon dioxide, and we are still studying the issue. We are not sure of the precise connection, but we think it may be more serious than the carbon dioxide question which was raised earlier.

Senator **Chafee**. Therefore, you say, don't do anything, because we can't get an international agreement. You said, Dr. Trivelpiece, that it would be symbolic, and I am not so sure that it would be symbolic.

Dr. **Trivelpiece**. The United States should take a position based on solid facts that are not disputable or debatable by those in the international arena.

Senator **Chafee**. Isn't this a solid fact?

Dr. **Trivelpiece**. I think that there seems to be some uncertainty, as nearly as I can tell.

Senator **Chafee**. There was no dispute among Dr. Watson, Dr. Rowland, and Dr. Hansen yesterday. Maybe DuPont would dispute it.

Mr. Chairman, do you have any other questions?

Senator **Stafford**. Mr. Chairman, I might have one or two.

Mr. Benedick, you mentioned the conference at Villach, I think it was. I wondered if the Soviet Union and the Communist bloc nations were present or represented at that conference?

Mr. **Benedick**. Senator Stafford, I don't have the list in front of me. I am not sure that they had scientists represented or not, but that is something that we can research.

Senator **Stafford**. Have there been, do you know, discussions with them with respect to both ozone depletion and the greenhouse gases?

Mr. **Benedick**. Yes; there have been. On second thought, I believe they were at Villach but, as I said, we can confirm that.

We do have, in fact, detailed ongoing discussions with the Soviet Union under our bilateral environmental agreement dealing with global climate, carbon dioxide, and similar environmental issues. These involved NOAA, the EPA, and other Government agencies, and it is part of an ongoing process; yes, sir.

Mr. **Thomas**. Senator, if I could just add to what Mr. Benedick said on that. My understanding from my people who participated, is that those countries were represented at the Villach Conference. But, more specifically to your point, under the international cooperative agreement that Mr. Benedick noted, we do have joint research on climate change with the Soviet Union. As late as November, when I led a delegation to Moscow, we discussed those at length with Soviet counterparts. The Director of the National Climate Program Office at NOAA was with me, and we had lengthy discussions concerning that joint research. He and I also spent a considerable amount of time with my counterpart, Dr. Israel, talking not only about what we were doing jointly on climate change, but also about our concerns concerning ozone depletion, and specifically the need for production information on fluorocarbon from the Soviet Union, which we have not received since 1980. I specifically asked him to try and persist in providing that information to us. We had quite a discussion on it.

Senator **Stafford**. Thank you very much.

Following up on what Chairman Chafee has been saying, what crossed my mind, since CFC's are escaping from automobile air-conditioning systems, and apparently are a principal source of CFC's in the atmosphere, and suspecting that maybe half of all the automobiles in the world are in the United States, or some very large percentage anyway, I think what Chairman Chafee was suggesting in terms of using a different form of CFC could have a considerable effect on the escape of that chemical into the upper atmosphere.

So, I think, John, you hit on an idea that is worth further consideration.

Finally, there was testimony yesterday, and I address this to anybody on the panel, that the metabolism of trees and plants are dependent on CO_2, just as animals are on oxygen. Therefore, I have wondered if in international discussions on greenhouse effect, if consideration has been given to reforestations in those parts of the world where the forests are being decimated at a rapid rate?

I don't know if anybody in this group would comment or not, but I would invite you to.

Mr. Benedick?

Mr. **Benedick**. Yes, Senator Stafford; we are actively engaged in a number of international fora, including the U.N. Food and Agriculture Organization, and the U.N. Environment Program, and also with the World Bank in developing reforestation projects throughout the world.

Senator **Stafford**. Thank you.

Thank you, Mr. Chairman.

Senator **Chafee**. One quick question of Mr. Thomas, and that is, the testimony from Mr. Brown and others has been that at these international conferences, the other nations drag their feet, don't see the problem, and aren't willing to participate in greater control of CFC's.

You would think that a meeting of the Environmental Ministers from around the world might be a way to break this impass. In other words, these people are far more sensitive to these issues than would be those who would be attending, the leaders of governments or their deputies attending some meeting. Would that be a way of raising the profile of this issue, do you think?

Mr. **Thomas**. Senator, the United Nations Environment Program's review of these issues is currently underway. It is one that I think has the attention of the various countries participating.

As I indicated in my opening statement, I have some concern about the need to elevate the level of discussion in that forum as we proceed in the timeframe we laid out at Vienna, which is over the next year, to discuss where we are, and what may need to be done, particularly as it relates to ozone depletion.

As to whether that would require a conference, or as to whether that would require a subgroup discussion at an Environmental Minister level, I don't know at this point. For instance, we have a workshop next week, as a matter of fact, jointly sponsored with the United Nations Environmental Program, and we are working through this international issue on ozone depletion.

I think that this is an issue that we need to address forthrightly; and that is, how do we elevate the discussion, which we will have to do, as we come to the same point a year from now that we were in Vienna—which is looking specifically at whether there is a need for a more directive protocol than we ended up with in the Vienna Convention.

Just one point of clarification on your preceding line of questioning. I have tried to make clear that I believe that the domestic issue and the international issue, as far as ozone depletion, need to proceed on parallel tracks, and that is the way we are proceeding with them as far as EPA is concerned, on parallel tracks, not necessarily sequentially. They are clearly interrelated. Clearly the issues that we deal with are interrelated, but you don't have to deal with them internationally before you deal with them domestically, or vice versa.

Senator **Chafee**. I certainly believe in that.

Mr. Benedick, where does the Vienna Treaty stand, and has that come out of committee?

Mr. **Benedick**. Yes, Senator Chafee; the committee did favorably report out the Vienna Convention, and it is now before the Senate. It is on your calendar, I believe.

Senator **Chafee**. All right, gentlemen, thank you very much for coming. We appreciate it.

The next panel will consist of Dr. Rabb, professor of history at Princeton University; Dr. Orfeo, chairman, Fluorocarbon Program Panel, CMA; and Dr. Michael Oppenheimer, EDF.

If those leaving would do so quietly so that we can get on with the testimony.

Dr. Rabb, we welcome you here, and we look forward to your testimony. Why don't you proceed.

STATEMENT OF DR. THEODORE RABB, PROFESSOR OF HISTORY, PRINCETON UNIVERSITY

Dr. **Rabb**. Mr. Chairman, a mere historian in the midst of all of these high-powered scientists has to feel something like Daniel in the lions' den, but I would remind you that in the biblical story, Daniel did have a somewhat different perspective when it came to grave warnings written by a finger on a wall.

What I would like to offer to you, as briefly as I may, is some small degree of perspective both upon the way scientists, it seems to me, interact with policy and with the world, and also on some historical examples that may shed light upon some of the issues that we face right now and in the near future.

I think the contrast between the testimony given to you yesterday, when a number of scientists made some clear and unequivocal statements, and the veiling of that testimony today, with discussions of complexity, uncertainty, lack of 100-percent knowledge, and so forth, is a classic example of precisely how scientists have, indeed, always proceeded since the days of the founding of modern science during the scientific revolution in the 17th century.

I think that there is an essential problem that you, as political leaders of this country, have to face in that there is a congenital hesitancy always in the scientific community in making unequivocal statements. Unless every contingency is under control, conclusions, predictions, can always be dismissed as premature. As one witness this morning said, we have to be fearful of overreaction, of hysteria, and so forth.

Where I think that comes from is very clearly from the origins of science as a discipline as we know it. At the time of the scientific revolution, Europe, which created modern science, was racked by vicious, religious, and ideological conflicts that really threatened to tear apart the very fabric of European civilization.

With the religious wars, and dreadful ideological divisions, about them, the scientists at that time made it a cardinal principle of their endeavor that they were going to be an oasis in a wilderness of hate and emotion. The very language of science had to be neutral; it had to be unadorned and objective.

Scientists were rightly proud that their great achievements in the scientific revolution thereafter crossed every imaginable hostile line. Protestants could talk to Catholics. Aristocrats mingled with plebeians, and so forth.

Even though many of those divisions have now largely vanished, the scientists continue to behave as though charged advocacy were a mortal sin. The few who do become involved in greater, larger causes are scorned and consigned to the fringes of their calling.

It is true that one has to be wary. Science has been brought to the service of some rather sinister masters. Geologists have seemed to justify racial superiority, biologists have condoned genocide, and so forth. But I don't think that this is the reason for the distrust of passion. Even the many groups of so-called concerned scientists have not really dented the careful distancing of the orthodox majority.

If neutrality is the watchword on limited issues, when you have portentous doomsday predictions, you have something that is almost by definition unacceptable. Unfortunately, a form of doomsday is exactly what climate might have in store for us.

If the scientific community has a fairly dismal record of rousing public understanding of the full implications of nuclear arsenals, then on climate it has virtually no record at all. If the average citizen were to be asked, on some kind of multiple choice, how to define the buildup of carbon dioxide, I suspect that the majority would probably think of it as some type of tooth decay.

This is where the objectivity and the commitment to research for its own sake have brought us. The studies multiply; the fascinating problems are uncovered and dissected; techniques of dazzling ingenuity are invented, and yet, even though I think there is, as you have said this morning, a very widespread consensus on certain predictions, there is no effort to raise alarm bells about the unmistakable and dangerous direction in which we are headed.

Why is that? Why is it that the few who have lit some beacons, and one example is Stephen Schneider's book, called "Genesis Strategy," why is it that people like that have been dismissed as insufficiently scientific, and tend to be regarded as untrustworthy?

If nobody can be 100 percent certain, and I think the notion that if we just keep going at research, if we go along a few more decades, or however long it will take, we will eventually be 100 percent certain, I think that is a chimera. Scientists are never 100 percent certain. Even Newton has been proven to be wrong. That notion of total certainty is something too elusive ever to be sought.

I think in the meantime we do have a pretty good idea. We know that if the carbon dioxide increase and the warming continue, America's Corn Belt will no longer grow corn. It may grow in Saskatchewan, but there isn't much soil up there. Trees that are now at home in the temperate zone, will not flourish where they now flourish, but who is going to plant them all further north, in their new home, and who is going to be ready to plant them all over again a few years hence when they migrate further north? That prospect is not a comfortable few centuries away, as we once thought, but it may be only 50 years and closing fast.

Why should people feel that they must delay when the prospect is not pleasant? The belief that we can sit back and do further research is, in my view, if anything, shattering. The evasions are quite extraordinary. In a world of fond hopes, perhaps the trend will not turn out as badly as the indicators now suggest. Maybe the model will prove to have been too pessimistic. Maybe the effects will be cushioned by adaptations similar to those that mankind has already undertaken when there have been huge dislocations, although, I should add, always with enormous individual and social suffering that have gone with them.

Could it be that we will somehow all muddle through, that it really is someone else's problem, perhaps the politicians', or perhaps that opposing trends will somehow nicely and meekly cancel each other out?

This caution, this insistence that we have to know more, even when we already know so much, the reluctance to predict profound dislocations, the trust in the saving discontinuity that somehow the trends might stop and turn in a different direction, is as damaging in my view as the obtuseness of those who cite a similar kind of discontinuity for different reasons, those who say that carbon dating is not accurate because there was a huge change in climate a few thousand years ago, and the evidence is that there were no rainbows before Noah's Ark.

If the scientists have, in a certain sense, a kind of professional problem, a historian can tell you that you are not going to get nice, neat, clear answers from scientists. I do think, nevertheless, that for the need to prepare, the need to think very directly and immediately about actions that can be taken, you can find another source.

Naturally, as a historian, I would suggest to you that you look at the past, which is littered with societies that were devastated by climatic forces. One example, for instance, is Sri Lanka around 1400. It was a wonderfully stable society. Its agriculture was destroyed by dwindling rainfall and it succumbed to a whole series of fundamental dislocations and resulting cultural changes which still to this day bedevil that island.

In Greenland, there was a flourishing European colony, which around 1700 disintegrated because of declining temperatures. We can see entire populations wiped out, or forced by immense destructions to move huge distances, totally reconstitute their economies and policies, and dismantle ways of life that were centuries old.

There are dozens of such examples, and they don't diminish in the 20th century as the mere mention of the Dust Bowl or the Sahel will remind us.

In my own field of specialization, 17th century Europe, there was a climatic change that accelerated the shift of power in Europe away from the Mediterranean, which had been the center of European civilization for 2,000 years, to the new powers of the north, in England and the Netherlands. It interrupted an enormous population and economic boom that might have stimulated the industrial revolution decades before it arrived, and it caused hardship at the local level throughout Europe.

The results of that was dreadful, dreadful hardship—starvation, plague, and also a tremendous rise in the powers of government which was now seen for the first time, really, in modern history, as the only body that could try to stave off economic and social disaster. It was the beginning of absolutism, and it was the beginning of the rise of central governments.

We look back at these eruptions, and we see fumbling and often futile efforts to come to terms with the upheavals. We see debilitating consequences, and yet none of those examples involves a climatic break of a magnitude, in the short term, that even approaches what the studies now tell us is likely to happen in the 21st century.

I wish we could look to scientists to issue unequivocal, unmistakable calls to tell us that we must move now. The only time that I can think of that happening in the 20th century is when Einstein wrote his famous letter of 1939 to President Roosevelt about German nuclear research.

I think the crucial thing there is not only the stature of Einstein who, of course, has not been replaced as a kind of leader of the scientific community, but also the identity of the recipient. I think that one of the major reasons that the Einstein letter worked was that it was a politician to whom he wrote, and that is why I think a beginning now is possible, to a large degree because of hearings like these.

What is needed above all is political leadership. In a situation lacking the obvious signs of disaster, but haunted by a distant menace, how else is the world to be galvanized? The baton must pass to those who can make the issue salient, can convince the scientists to face up to these demands, in other words, to our political leaders.

The tools you need are certainly at hand. There are dozens of studies of peoples whose lives have been shattered by natural disasters. We have analyzed strategies that have saved communities, and reactions that have merely made bad times worse.

It is not too difficult, for instance, to learn why the potato fungus that caused starvation in Ireland in the 1840's had a far less malignant effect in those very same years on the Netherlands and on the Dutch who ate just as many potatoes as the Irish, but had no starvation, no massive emigration at all.

It is a matter of political reactions. It is a matter of the policies that are undertaken by the governments at the time. We have one enormous advantage even over the well-organized and environmentally astute Dutch. We have some foreknowledge which they, in 1840, did not have.

We can, therefore, consider now, while there is still time, how we must address the issues that confront us. What will we want to do when Washington gets Miami's climate? Mr. Chairman, I would suggest, that just as war is too important to leave to the soldiers, so the environment is too important to leave to the scientists.

Thank you.

Senator **Chafee**. That is a powerful statement, Dr. Rabb. I will say this, in fairness, it was the scientists yesterday who sounded the alarm, and it was the politicians, or the governmental witnesses, who put the damper on it, as you heard today from the panel.

Dr. **Rabb**. You mention that they are politicians, but I would prefer to call them, if you will pardon me, Mr. Chairman, the bureaucrats.

Senator **Chafee**. That may be, but I think the hat must go off to the witnesses we had yesterday, who didn't hesitate at all to indicate a deep concern even though all of the evidence wasn't in. We heard, as I said, from Dr. Watson, Dr. Rowland, Dr. Hansen, Dr. Woodwell, Dr. Wunsch, and Dr. Leatherman. All spoke right out and said, we have a disaster on our hands here, unless we do something.

So, I wouldn't be too harsh on the scientists, certainly the ones dealing with this issue have, indeed, spoken out and vigorously.

Just out of curiosity, just what did the Dutch do about the potato blight that the Irish didn't do? How did they handle it, in a half a minute or less?

Dr. **Rabb**. In even less than a half a minute, they immediately started planting alternative crops. They imported grain, which was in fact not affected by the fungus, and they essentially forced their people to change their eating habits. They essentially said to their people: You can starve, or you can eat the grain. The British Government, which ruled Ireland, and had, as you may know, a rather lowly view of the Irish, didn't even bother.

Senator **Chafee**. Thank you, Doctor, and I will have some questions for you.

Dr. Orfeo is our next witness. Why don't you proceed, Dr. Orfeo.

STATEMENT OF DR. S. ROBERT ORFEO, CHAIRMAN, FLUOROCARBON PROGRAM PANEL, CHEMICAL MANUFACTURERS ASSOCIATION

Dr. **Orfeo**. Thank you, Mr. Chairman. Let me, on behalf of the panel, express our appreciation for the opportunity to participate in this hearing.

For the record, I am a member of Allied Signal Corp. technical staff, and I am also the chairman of the Fluorocarbon Program Panel of the Chemical Manufacturers Association. The panel is an international group of scientists which represents 19 free world chlorofluorocarbon producers from 10 countries and includes the 5 U.S. producers.

This panel was started back in 1972, when we first became aware that chlorofluorocarbons [CFC'S] were increasing; that is, their concentration was increasing in the lower atmosphere. It is fair to point out that this was 2 years before the Rowland-Molina theory was published. We have been concerned, and we continue to be concerned, about the potential impact of the emission of these products.

Since 1972, this panel has funded over 18 million dollars' worth of research, and, in support of this activity, an equal amount of money has been spent; so, the expenditures have been about $40 million.

This year, what this panel has focused on, is obviously the Antarctic ozone phenomenon. There is an observation there, and we don't know what causes it. We have started research in this direction.

Early this year, there was a joint workshop cofunded between NASA, NOAA, and the panel in which various explanations for this phenomenon were presented. The criteria to test these hypotheses were identified and programs are being put in place to verify them. We feel that within 2 years that question will be answered.

We have had one monitoring system which takes care of trying to determine what happens to ozone. There are ground-based monitoring stations that go back as far as 1927 that have been looking at the total column concentration of ozone.

About 10 years ago, we started to do research on trying to analyze these data and see if we could find trends. That work is still ongoing, but what we can say today using the most sophisticated treatment of these data is that analysis does not show any change in the natural behavior of total column ozone.

At the same time, the same analytical technique was used to look at the profile data. There is an indication at the 40-kilometer region, which is an indicator of the possible effect of chlorofluorocarbons, that there is a negative change. There is a trend that suggests that there is a decrease up there. It is in qualitative agreement with what the models calculate. There is a problem with the data. It is not as good or as reliable as the total column measurements that are made. There is still work to be done to sort that out.

The measurement of ozone identifies an effect, but it does not give you any idea of what is causing this effect. At the same workshop where we looked at the possible explanations for the Antarctic ozone phenomenon, we also considered the feasibility of establishing an early detection network to identify the key trace species, the equipment that would be needed to measure these species, and where the stations should be located, in order to be able to identify a cause and effect relationship. It was pretty well agreed as a consensus among the scientists there that this network is feasible, and programs are being put in place. We have started to cooperate with both NASA and NOAA to see that this network is implemented.

Another aspect of the panel's program is the heart of this whole problem—the model. The model has to account for complex interplay between dynamics radiation, and chemistry, and describe this interplay telling us what happens in terms of ozone changes, temperature, whatever.

There is a problem. We are concerned about the ability of models to reproduce the present day atmosphere. There are serious discrepancies, which have to be resolved if we are going to take a model and use it to forecast. If it can't reproduce the present day atmosphere, we can't have a high level of confidence in its ability to forecast the future. We have an ongoing program on model development, to try to resolve these differences, so that we can have greater confidence in those calculations.

If I can summarize, first and foremost we must resolve the cause of this Antarctic ozone phenomenon. There is no explanation for it now, and the explanation will have a very direct bearing, certainly,

pages tightly bound

on the way that we look at this problem. The program is in place to test the hypotheses that have been proposed. We are working closely with NASA and NOAA to implement these programs, and it will probably take 1½ to 2 years to get these data out, and resolve the key points.

Physically, it is very difficult to take equipment down to the Antarctic. It is an area in which measurements get to be a little bit sticky in terms of the rigors of the environment. Some of the equipment that has been proposed has never been tested down there. We may have a lag time in getting the equipment operational.

As I indicated before, the most sophisticated analysis of total column ozone data show no change in the natural behavior of ozone until 1985. There is change in the variability but this is anticipated. I indicated that there is a trend at 40 kilometers which tends to be negative. It still has to be sorted out because of the quality and reliability of the data.

We also think that it is vital that we put together an early detection network, not only because of the fluorocarbon issue, but because there are other trace gases that contribute to either how ozone will vary or contribute to the greenhouse effect. How these trace gases will grow in the future must be monitored, so that we can understand their impact. We are cooperating with NASA and NOAA on this problem also, and we urge very strongly that this effort be supported.

We still feel that there are serious discrepancies between observations and model calculations. We feel that these have to be resolved before we can put a high level of credence in forecasts for the future. We are committing money to try to resolve some of these discrepancies in terms of model reliability.

To sum it all up, we believe that there are very important gaps that remain to be resolved as far as the science is concerned. We plan to continue our research, and we encourage you to continue to foster and fund government research, particularly in the areas of establishing the early detection network and, improving instrumentation to monitor ozone. The techniques that we have available today all have problems. There is equipment in the research stage that will improve the capability to measure total column ozone and profile ozone. Money should be spent to develop and commercialize equipment so that it can be available. Thank you.

Senator **Chafee**. Thank you, Dr. Orfeo.

Senator Stafford, I know that you have another engagement, so if you would like to proceed with some questions, it would be fine.

Senator **Stafford**. Thank you, Mr. Chairman, I just have one question.

Dr. Orfeo, in your prepared statement, you say, "continued releases of CFC's will not pose a significant threat to the environment during the time required to gain a better understanding of the science."

Did I understand you to say, and correct me if I am wrong, that 2 more years would give us sufficient understanding of this problem?

Dr. **Orfeo**. I don't think that I put a time in there.

Senator **Stafford**. Would you be able to give us some timespan?

Dr. **Orfeo**. I think that the timespan that I stated was to look at the immediate problem that we have as far as what is happening down in the Antarctic. There have been observations by several techniques that there has been a very dramatic change in ozone over a period of years. We don't have an explanation for this yet. I think that some people feel that they have an explanation, but there is no evidence to support any. We know that we have to try to sort out these different hypotheses that have been proposed. Two years is the time that it will take to get it done if all goes well. That is what I meant by the 2-year period.

Senator **Stafford**. All right.

Thank you, Mr. Chairman.

Senator **Chafee**. Thank you, Senator Stafford, for attending.

Now we will have Dr. Oppenheimer.

STATEMENT OF DR. MICHAEL OPPENHEIMER, SENIOR SCIENTIST, ENVIRONMENTAL DEFENSE FUND

Dr. **Oppenheimer**. Thank you, Mr. Chairman.

I am a senior scientist with the Environmental Defense Fund. My expertise is in the area of atmospheric physics and chemistry. I was previously employed as a physicist at the Harvard Smithsonian Center for Astrophysics, at which time I was involved in the early planning for the upper atmosphere research satellite mentioned by Dr. Graham previously. I was also involved in NASA Atmospheric Explorer Satellite Program.

My testimony today, which I will summarize, will focus on climate change, a problem which if left unchecked will come to dominate all others in its effect on our environment.

From the perspective of human history, as we have just heard, these changes will be rapid, costly, and largely undesirable. The viability of many ecosystems is at stake, as is, perhaps, the viability of civilization as we know it.

The changes may occur, in fact, appear to be occurring, faster than our knowledge of them is increasing. Yet, we currently know well how to limit these changes. Since the consequences of ignoring climate change will be severe, it is time for the U.S. Government, along with governments of other nations, to come to grips with the problem. It is time to act now.

We do not need a comprehensive understanding to undertake action. It is time to develop policies to limit climate change. Let me make the following brief points:

Climate change by the early 21st century, as you heard yesterday, will take us to climate conditions outside of previous human experience. Although the ecological effects of large-scale climate change are not well understood, there is no doubt that large changes will occur, and that some ecosystems, which this committee has fought so hard to protect, will simply disappear. These changes present a risk of unacceptable consequences to human civilization.

Synergistic interactions among climate change, stratospheric ozone reduction, acid deposition, and other pollutant stresses will amplify and accelerate the threat to the biosphere.

I would predict that we would see the effects of climate change relatively near in the future, perhaps in a couple of decades, due to these synergistic interactions. I would propose that midlatitude forests, which are already under severe pollutant stress, are one place where early changes will occur, and that we should designate midlatitude forests as an early warning ecosystem and watch them very carefully. We cannot afford their further collapse.

Substantial climate change appears to already be "in the bank," so to speak, so the time to consider policy to limit climate change is now. Actions to limit greenhouse gas emissions will slow climate change by keeping the so-called infrared window open as much as possible, allowing our knowledge to expand, hopefully faster than the climate is changing, which is not the current situation.

The process of international policy development to limit and adapt to climate change has begun through the followup to the Villach meeting under WMO, ICSU, and various private organizations, including my own. The U.S. Government should aggressively encourage, support and participate in these activities. Governments can now slow climate change on their own by a variety of actions which are generally beneficial from several perspectives such as limiting dependence on fossil fuels, and acting to preserve and increase forests.

Research on climate change in general, and its ecological consequences in particular, must be expanded rapidly. Nothing is of higher priority than determining how fast we are narrowing the niche humans occupy in the natural system.

But by the time a clearer picture emerges, we will be brought into unacceptable levels of climate change, so that at the same time, we should act to limit climate change.

I want to comment very briefly on some of the earlier testimony. It was perhaps surprising to sit and watch five Government witnesses speak for less than 40 minutes on this subject. What we got was massive underreaction. These people, these individuals, these Departments, are the trustees for us, essentially, on this problem, and they exhibit what I would call a spectacular lack of ideas on how to proceed, and a perplexing sense of lethargy on what is apparently the most important long-range problem that we have to face.

Mr. Thomas from EPA spoke well about the need to intervene in the problem, yet he did not speak so clearly about the need to develop policies to protect the environment with specific government actions explored.

The witness from Commerce mentioned no attempts to analyze the economic implications of climate change, nor did he discuss the need for a massively increased research program.

Dr. Graham, from NASA, gave no indication of a very needed shift in this agency's priorities, given its current problems. My view is that NASA should go back more in the direction of doing the one thing that it knows how to do very well, which is scientific research. Scientific research and monitoring the Earth is absolutely essential if we are to anticipate and act properly on climate change.

The witness from State mentioned acting carefully to avoid unnecessary cost of action; but what about the cost of inaction, the cost of delay.

The witness from DOE didn't seem to have very many ideas about what to do.

This sense of lack of urgency is striking, this sense that there is no job that can be identified that needs to be done quickly. There are certainly prudent actions that can be done right now—increases in energy efficiency, making chlorofluorocarbons that are used in refrigeration recyclable, and other actions.

Let me conclude by just saying that I fully support, Senator Chafee, the recommendations which you mentioned yesterday. We need to support international efforts to develop a Greenhouse Gas Convention. The Government agencies need to develop policy alternatives expeditiously for limiting greenhouse gases and protecting forests.

We need to massively increase support for research on climate change and in particular on its ecological effects. The Government support for research in ecology right now is what I would call pathetic. We need to push for a meaningful limitation on fluorocarbon production in the context of the 1987 convention.

We need to encourage actions internally in the United States, which increase efficiency in use of energy, and in the use of materials.

Finally, with regard to climate change, we cannot afford to just let it happen. The costs of a nonpolicy will be enormous. Let us set out now to determine a reasonable course for greenhouse limitation before we are overtaken by the dire consequences of inaction; otherwise unacceptable levels of climate change may be in the bank before we have even understood what we have wrought. Thank you.

Senator **Chafee**. Thank you very much, Dr. Oppenheimer. I share your deep concerns.

Dr. Orfeo, we have certainly had some testimony that would refute your statement that "continued releases of CFC's do not pose a significant threat to the environment during the time required to gain a better understanding of the science."

I wasn't sure, in your answer to Senator Stafford, when he asked you how long you thought that would take. What was your answer?

Dr. **Orfeo**. My response to that was to the specific problem in terms of the Antarctic ozone phenomenon. As best as we can think right now, we have to get the equipment down there.

Senator **Chafee**. Did he limit his question to the Antarctic ozone situation? Let me rephrase it, then.

Dr. **Orfeo**. He asked me where I came in with the 2 year timespan, and I had referred to the Antarctic ozone problem.

Senator **Chafee**. Let me ask you this. We had some testimony yesterday from Dr. Rowland, I believe, in connection with the freon gases used for automobile air-conditioning, and you must know a lot about that subject. He indicated that a substitute was available, that cost something more, but not significantly more. Is that an accurate appraisal judging from your experience?

Dr. **Orfeo**. I think that the way to answer that one is that—I have to take off my Fluorocarbon Panel hat, and put on my Allied

Corp. hat, if you will. I can't speak for the industry; I must speak for my own company.

Senator **Chafee**. Sure.

Dr. **Orfeo**. We undertook programs in 1975–76 to look into the possibility of developing alternatives. There was a rather intensive campaign that was carried on for a 5- or 6-year period. The activity level has dropped off considerably in the last 3 or 4 years, but we have maintained a modest research effort, primarily in cooperation with some of our customers. Recognizing that we must put certain performance standards on the material we are looking at as a replacement, we must ask: is it environmentally acceptable; is its cost performance capability equivalent or superior to the existing product: is it safe to use; and will it have health effects?

Senator **Chafee**. Did you say, its cost performance?

Dr. **Orfeo**. Yes. There is a performance that it has to meet, a performance standard, and then there is a cost, and you have to look at both. You can't separate them, if you will.

Senator **Chafee**. All right, go ahead.

Dr. **Orfeo**. If you look at all of these, we really didn't find anything that could meet all of these criteria.

Senator **Chafee**. He acknowledged that the cost would be somewhat more, although as a percentage of the total cost of an air-conditioner, it is relatively modest, that is the incremental cost.

Dr. **Orfeo**. I don't know where he gets his cost figures, but there were estimates at one time that it would be a minimum of five times as much, and possibly higher than that. To go back to how this cost is arrived at, and really the basic problems that we run into sometimes, is the process of deciding whether you have something which is commercially viable. You have to consider first of all, the availability and cost of the raw materials to make this compound. Second, if you have a process in mind, will it lend itself to an existing facility, or must you commit extensive capital funds to build a new plant? Third, does it lend itself to the quality of product that you need. At the risk of being self-serving, fluorocarbons are unique because they can be produced in large quanties at purity levels which are sellable.

One must continue to meet that standard. Byproducts are inevitable in the course of making a product. It is very rare indeed that you find a process where only one product is formed. Normally there are byproducts that form. How do you handle these other environmental problems that you have created?.

In the process of developing a method of producing these fluorocarbons, do you have a byproduct which may be unsafe and have a high-toxicity level? You have to concern yourself with safety when you consider whether a process is viable or not.

Senator **Chafee**. All right, you have all of these problems, but what do you come up with as an answer?

Dr. **Orfeo**. We still don't think that we have a product that can be a replacement in terms of meeting the performance cost/benefits that have to be assigned here.

Senator **Chafee**. In this area, I work with kind of an innocence that is based upon the belief that when American industry is challenged sufficiently, they can produce something that meets the requirements. It may be more costly, and I think that this would, undoubtedly, be more costly, but as long as everybody has to pay the price; that is, you can't have the Japanese bringing in a car that doesn't meet the standard, or the Europeans, or whoever it would be.

Here is my question to you. If we should say to you, we are going to ban all of the fluorocarbon. It is a fluorocarbon that you use in your air-conditioning in automobile; isn't it?

Dr. **Orfeo**. Yes; it is fluorocarbon 12.

Senator **Chafee**. We are going to ban fluorocarbon 12, and you can't use it in any automobile air-conditioner starting in 1989. What would happen? What could you do?

Dr. **Orfeo**. You are asking me to make a business decision here.

Senator **Chafee**. No; I am not asking you to make a business decision. I am asking you to make a scientific decision; that is, does that end all automobile air-conditioning, or would you come up with something?

Dr. **Orfeo**. I suppose that we would have to go back and find something, and it may not be in terms of a new refrigerant; if you will, it may be the design of a new type of air-conditioning system that doesn't necessarily have to use fluorocarbon.

Senator **Chafee**. Dr. Rowland mentioned a fluorocarbon 22, or something like that, I am not sure what it was.

Dr. **Orfeo**. I think I remember him mentioning 22 yesterday. It is a higher pressure refrigerant, and its utility would depend on a complete redesign of the air-conditioning system—the mobile air-conditioning system.

Senator **Chafee**. I know that it is expensive, and all of that, but after all, you design a new car every year.

Dr. **Orfeo**. I am not at General Motors, and they are the ones who would have to answer that question, because it would be a capital commitment on their part, and not on the part of the fluorocarbon producer.

Senator **Chafee**. What is the answer to my question?

Dr. **Orfeo**. I have tc tell you that the use of fluorocarbon 22 will require a change in the system design, and it would have to be a very drastic change.

Senator **Chafee**. All right, I will acknowledge that. Would fluorocarbon 22 meet the requirements that you previously set forth, safety, environmentally safe, and and acceptably priced?

Dr. **Orfeo**. As we understand it, fluorocarbon 22 is certainly environmentally acceptable from an atmospheric point of view. It is a commercially available product, albeit a little more expensive than 12, but that is not critical. What is not certain is: Can you design a system that can handle the higher pressures and temperatures that are going to evolve from running the thermo-dynamic cycle? By the very nature of the beast, it has to run at very high pressures, and the molecule is so configured that it will generate high temperatures. There are two factors to concern yourself with; one is a safety problem that you will be generating pressures in excess of 500 pounds per square inch.

Senator **Chafee**. As compared to what pressures now?

Dr. **Orfeo**. Three hundred and some odd pounds with the fluorocarbon 12.

Senator **Chafee**. So, you would be going from 300 to 500.

Dr. **Orfeo**. Yes; and it is a difference.

Senator **Chafee**. What are the problems with an ordinary, nonmobile refrigerator; is that easier to solve or more complicated?

Dr. **Orfeo**. In some respects, the system is somewhat simpler in terms of the demands on it. You have a very robust refrigerant in the case of 12, which is normally used in refrigerators, although 22 is used sometimes. Here again, it is the same basic problem because of the thermodynamic differences in terms of the cycle over which it has to operate. The heats and pressures that are generated will require a redesign of the system. I am not a refrigeration engineer, but if I had to make a guess, I would say that you would have to redesign to handle the higher pressures and temperatures and it would be at a cost penalty. Someone would have to pay for that improvement, and it would be the consumer. It is primarily in the design of the system.

Senator **Chafee**. I see.

Dr. Oppenheimer stated that what we have already let loose is so destructive that we had better do something now, instead of waiting around for *x* number of years more, just pushing more and more of these gases and fluorocarbons, CO_2, and everything else out there. We have to do something now.

Dr. Rabb, what do you say about that?

Dr. **Rabb**. I agree absolutely, Senator. I should say, first of all, that because of the pressures of time I didn't convey in my spoken statement, all the nuances about the scientists that are contained in my written statement. I assure you that I certainly do recognize that the fact that we all know what the problems are is very much the result of the warning that a few scientists have issued to all of us, and what Dr. Oppenheimer said a few minutes ago exemplifies that.

The trouble is that because of the nature of scientific discourse, it is always going to be possible to come back with statements such as the ones we have heard just now and earlier this morning, that we are not there 100 percent. There are all kinds of issues that still need to be studied, and so forth.

The only response that I can bring to that is to adapt a very famous passage from one of the greatest scientists of the 17th century; namely, Blaise Pascal who, as you may know, did not only write on scientific matters, he was a very great philosopher and religious thinker as well.

There is the famous wager that Pascal put forward in which he said: Maybe God doesn't exist, but let's at least go ahead and believe that He exists because what do we have to lose? If we do believe in him, then maybe we will gain salvation, and if that is a misplaced belief, we haven't lost anything, whereas the dangers of not believing in God are really far greater if we come out the wrong way on that one.

I would argue similarly here. We have to believe, like Pascal urged us to, that there is a danger, as some of these scientists have said, not all of them—the scientific community is not united. There are scientists who are worried about a cooling. I think that there are all kinds of contrary pieces of evidence, data not in, and so forth.

Right now, I think the data are certainly sufficient for us to assume that very significant disruptions of human society are likely to happen, and there are two prongs, I think, to what the political leadership ought to be looking at. On the one hand, the issues that you have been looking at; namely, how do we slow this down? What kind of regulation should be put forward?

The other is planning and studying for what this is going to do to society. Assume that the measures you can take are not in time. Assume that the measures you can take are not going to be sufficient to prevent certain fundamentally ill-effects overtaking the United States over the next 50 years.

There ought to be also some social planning. I think that if all human civilization is going to be wiped out, there is not much that we can do, but there are many disruptions, fairly catastrophic but short of that, and the question is, how do we begin to plan the changes that may ensue, taking various scenarios, at least the safest scenarios, of what warming is likely to do to us?

Dr. **OPPENHEIMER**. Senator, could I comment on that also?

Senator **CHAFEE**. Yes; Dr. Oppenheimer.

Dr. **OPPENHEIMER**. This whole thing, it has been said many times, is like an experiment, only in this experiment there is a funny lag. The scientists are at one end of the equipment, and we turn it on and run to the other end to make the measurement, and we make a model for what is going to happen. Unfortunately, it may be 20, 30, or 50 years before we can make the measurement over here at the other end of what is going to happen, by which time we have already, as you said, got "in the bank" a lot of climate change. We may have a degree or so centigrade in the bank right now. That degree or so puts us in a situation which will exceed human experience as far as the climate is concerned.

We might well be brought into a situation which is already rather unacceptable. We can't afford those kinds of risks. This is a different type of problem, and we just can't afford to sit back and wait.

Senator **CHAFEE**. That is the way I feel. I don't think that there is anything similar to this that we have ever encountered before. Human beings have participated in plenty of destruction on this globe, but it is always of a less consequential, less encompassing nature.

Mercury was dumped in the Bay of Tokyo. Eventually, they were able to stop that, and the oceans, hopefully, were able to take care of it. Nuclear bombs have gone off, but it seems that the system somehow has been able to handle it. We are very much aware of all the dangers that come with it. But this is something far different, as Dr. Oppenheimer said. Just the degree change is incredible in its consequences.

I share the concerns that all have voiced. Does anybody have any other contribution to make?

Dr. **ORFEO**. Just one last one.

Senator **CHAFEE**. Surely, Dr. Orfeo.

Dr. **ORFEO**. I would make the point that this is a trace gas problem, so you have to treat it in its entirety. It is not just fluorocarbons. It is the methane, the nitrous oxide, and they all contribute to the greenhouse effect in one shape, form, or other.

The magnitude may be in question in terms of changes in total column ozone, and in the redistribution of the profile. Eliminating one of them will not cure that problem. There will be changes.

Senator CHAFEE. I think that we recognize that. If we were masters of the world, we would do something about the carbon dioxide, but we are not. We can't tell the Soviets what to do, or the Chinese what to do. But it seems to me that that isn't an excuse for no action at all on the part of the United States. That is why I find fault with the view that if we take action, the Europeans may not, or the other nations may not, but that is not a call to inaction it seems to me. We ought to do what we can, and set an example.

I can't believe that the fact that the United States has banned CFC's in the aerosol cans hasn't inspired others. Indeed, it is my understanding that they have. The Canadians are with us. The Scandinavian countries are with us, and some others, and others will catch on.

I also can't believe that the power of the United States as a trading nation can't exert some influence and effect on what other nations do. I wish I had brought that up with Mr. Benedick. I think that we have mammoth influence just because we are such a massive force in world markets.

We thank you all very much for coming. We appreciate the views that you have expressed. Thank you very much.

[Whereupon, at 12:05 p.m., the subcommittee adjourned, to reconvene at the call of the Chair.]

[Statements submitted for the record follow:]

TESTIMONY OF
LEE M. THOMAS
ADMINISTRATOR
U.S. ENVIRONMENTAL PROTECTION AGENCY
BEFORE THE
SUBCOMMITTEE ON ENVIRONMENTAL POLLUTION
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
U.S. SENATE

June 11, 1986

Good morning, Mr. Chairman and members of the Subcommittee. I am pleased to be here to discuss with you our understanding of the changes in the chemical and physical make-up of the earth's atmosphere, the possible public health and environmental implications of these changes, and EPA's efforts to understand and address these concerns.

Although we at EPA usually focus on pollution that directly affects land, water, and the air we breathe, we must not ignore the environmental significance of changes now occurring in the composition of the earth's atmosphere from our industrial activities.

Our atmosphere plays a fundamental role in shaping and protecting our planet's environment. Changes in its delicate chemical and physical balance could possibly lead to two separate but related problems. These problems are the focus of my testimony.

First, the ozone layer of our stratosphere currently protects us from exposure to most of the sun's damaging ultraviolet radiation. Partial depletion of the ozone layer would increase our exposure to the potentially damaging part of the solar spectrum, leading to adverse health and environmental effects.

Second, certain gases in the atmosphere, known as greenhouse gases, form a "thermal blanket" around the earth by blocking part of the infrared radiation reflected from the earth's surface. The presence of these greenhouse gases act to maintain our planet's current moderate temperature. Increases in the amount of these greenhouse gases would result in a rise in the earth's average temperature.

Based on our current understanding, we believe that a small change in the amount of UV-B radiation striking the earth and/or a change in the earth's mean temperature could have significant environmental and health consequences. The fundamental scientific uncertainty is no longer, are these phenomena real, but rather, the question is, at what rate are they likely to occur? In addition, we need to better understand the full nature of the impact of these changes and the possible options, both in the near and long term, for managing these risks. We do not yet have complete answers to these questions, although recent efforts have resulted in substantial progress.

In considering these issues, we believe that it is essential to distinguish between the scientific process of risk assessment and the public policy process of risk management. In these cases, risk assessment looks specifically at the scientific and technical evidence to determine the health and environmental risks associated with climate change or depletion of the ozone layer. Risk assessment will have a particularly important role in evaluating the uncertainties associated with this issue.

Risk management, on the other hand, uses this risk assessment information and determines the options available to address these problems. The course of action which the U.S. ultimately chooses, which will take into consideration the full spectrum of associated economic and social impacts, will have to be one that recognizes both the national and international aspects of the issue. Through the risk management process, and pursuant to our mandate under the Clean Air Act, we will make a determination of whether our nation will need to take additional specific actions to control risks related to stratospheric ozone depletion. EPA will make this decision publicly, with ample opportunity for comment by all interested parties.

Yesterday you heard a detailed analysis of aspects of these issues related to the atmospheric sciences. I will therefore not repeat this in my testimony. Let me instead discuss what I believe to be some of the unique factors associated with both stratospheric ozone depletion and climate change.

Both issues are clear examples of a "global commons" environmental problem. All nations are responsible for contributing to recent changes in our atmosphere -- although the industrially developed nations must shoulder more of the responsibility. However, all nations would be affected by depletion of the ozone layer or by global climate changes. Therefore, the international community will need to cooperate in any effective solution to these problems. The U.S. has already taken a leadership position by banning non-essential uses of aerosols.

Moreover, we cannot simply focus our attention exclusively on the atmosphere and hope to fully understand what the future will hold. We must also work to obtain a better understanding of the biosphere and the oceans and how these systems interact.

Nor can we expect to understand the full implications of the environmental changes that appear possible over the coming decades. For example, some climate models suggest as much as a one degree centigrade surface temperature change by the turn of the century. We recognize that this would be a significant change.

We cannot state with certainty what the full range of health and environmental risks are likely to be from either of the problems. We can, however, begin to identify areas likely to be affected. They include: human health, agriculture, forests, wetlands, coastal development, and endangered species.

Both the climate change and stratospheric ozone depletion problems are unlike some traditional environmental problems because such changes, if they occur, are likely to be irreversible over a period of many decades. Several of these gases have atmospheric lifetimes of over 75 years, during which time their impact on the environment could not easily be reversed.

Given the scientific uncertainties, we recognize that any action taken now has a cost associated with it which, as we learn more, may prove unwarranted. Thus, any analysis of whether actions to slow emissions are necessary must compare the costs and risks of acting now or acting later.

I would like to now move from discussing the general characteristics of the issues to focusing on EPA's specific involvement.

Ozone Depletion

As you are aware, back in 1977 when the Clean Air Act was last amended, a comprehensive section (Title II, Part B) was added dealing with stratospheric ozone protection. This section called for extensive research and reporting by several agencies and expanded international cooperation. Section 157 also sets forth a regulatory provision requiring that the Administrator of EPA "shall propose regulations for the control of any substance, practice, process, or activity (or any combination thereof) which in his judgment may reasonably be anticipated to affect the stratosphere, especially ozone in the stratosphere, if such effect in the stratosphere may reasonably be anticipated to endanger public health or welfare."

On January 10, 1986, EPA published in the Federal Register notice of an expanded program to meet our responsibilities under this section of the Clean Air Act. While the program does not commit EPA to taking specific actions to further regulate CFCs or other ozone modifying gases, it does initiate EPA's rulemaking process which will provide the basis for a decision concerning whether additional controls are warranted. The plan commits us to making a final decision by November 1, 1987. The Agency is under a court order to make a decision by that time.

The Agency's Stratospheric Protection Plan contains both a domestic and international focus. On the domestic front:

- o We are committed to a final decision concerning the need for additional regulations by November 1987;
- o We are re-establishing the Interagency Coordinating Committee on Stratospheric Ozone Protection to ensure proper coordination of research across all federal agencies;
- o We have held one domestic workshop on economic aspects of this issue, and have a second scheduled for late July.
- o We are calculating the effects of UV-B on agricultural plants and aquatic organisms, and have a small effect on human health effects.

On the international front:

- o We actively supported the Vienna Convention for the Protection of the Ozone Layer, pending before the Senate for its advice and consent. This Convention provides for international cooperation and support for scientific research on the stratospheric ozone issue.
- • We are examining a full range of international strategies as part of our risk management/risk assessment process and will decide our negotiating position on that basis when international negotiations resume in the fall. Consequently, we have stepped back from our previous unsuccessful efforts to persuade other nations to follow our

lead and ban the use of chlorofluorocarbons in nonessential aerosol products.

- We are actively participating in the United Nations Environment Programme (UNEP) workshop on economic issues related to ozone protection and are co-sponsors of an international conference on Health and Environmental Effects here in Washington next week. I would like to personally thank you, Mr. Chairman, for your participation as a featured speaker at this conference.
- We are moving in step with the timetable established by UNEP so that we will have an adequate information base for deciding our international and domestic positions.

We recognize that several important factors must not be overlooked. To the extent that action is needed, it is essential that the international community move forward to deal with these issues together. Further, we realize that our analysis must include all trace gases that may modify the ozone layer and not just CFCs. In the case of CFCs, we recognize that they are extremely important chemicals used across a broad spectrum of industrial and consumer goods. For some uses, we recognize that no effective alternative chemical currently exists.

Finally, we recognize that the potential risks we face are generally long-term and that, if action proves warranted, any regulatory approach selected should be structured in a way which minimizes costs and disruption to producers and users.

In summary, I feel that our recently initiated stratospheric protection plan provides a comprehensive basis for us to move forward to evaluate the need for additional controls consistent with our duties under the Clean Air Act.

Climate Change Activities

In your pre-hearing questions to EPA, you asked whether climate change should be viewed as an environmental issue. As I discussed earlier in this statement, the potential environmental implications of the rate and magnitude of global warming now predicted by climate models can only begin to be assessed. Yet, without this knowledge of the possible implications of continuing to add greenhouse gases to our atmosphere, any decision on future policy action would be premature.

Because several other agencies have extensive and quite excellent research programs aimed at understanding important aspects of this problem, I am going to limit my remarks specifically to those areas where EPA has sought to contribute.

Over the past four years we have supported a small, but active program focused on:

- evaluating likely future trends in emissions of non-CO_2 greenhouse gases (e.g., chlorofluorocarbons, nitrous oxides, methane);
- developing climate change scenarios (e.g., changes in temperature, water availability, and sea level) that could be used by our researchers and others to estimate possible economic and environmental effects from such climate changes; and

- **working with outside groups to better understand the potential effects of climate change scenarios on such activities as forest productivity (with National Forests Products Association and Conservation Foundation); electric utility planning (with EPRI and EEI); salinity of drinking water (Delaware River Basin Commission).**

Through these case studies, we hope to begin to understand the possible economic and environmental implications of climate change.

To augment our current efforts, I have recently established an EPA Climate Change Working Group that cuts across several offices within the Agency. This group will report to me on what additional activities, if any, might be initiated to effectively deal with this issue in a timely manner. I expect that we will focus our resources on the following areas of policy and research needs:

- estimating trends in greenhouse gas emissions and determining possible control options;
- developing and evaluating improved scenarios to be used for estimating potential environmental effects of trace gases; and
- expanding long-term research focused on possible environmental effects.

In addition to specific research and analysis, we also intend to work through the Interagency National Climate Policy Board and Program to ensure that the entire federal research effort in this area is responsive to environmental concerns, and to expand our international efforts related to climate change. While supporting the recent Villach Conference statement on climate change, we fully recognize that increased understanding of this issue is essential before any international regulatory action will be possible.

To conclude, I would like to emphasize both my deep concern about the potential environmental risks associated with these issues and the complexity of developing a response which effectively responds to their unique characteristics. Despite these complexities, I want to assure you that we are moving forward in a timely manner to responsibly deal with these issues.

I will be pleased to attempt to answer any questions you may have.

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TESTIMONY OF
CLARENCE J. BROWN
DEPUTY SECRETARY
U.S. DEPARTMENT OF COMMERCE
BEFORE THE
SUBCOMMITTEE ON ENVIRONMENTAL POLLUTION
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

JUNE 11, 1986

Mr. Chairman and Members of the Subcommittee, I am pleased to be here today to discuss the role of the Department of Commerce, specifically the National Oceanic and Atmospheric Administration (NOAA), and the National Bureau of Standards (NBS), in investigating the "greenhouse effect" and ozone depletion.

I am not an expert on these questions, and I will not attempt to answer technical questions or make predictions. The Department of Commerce does have experts on many aspects of global change in climate and the greenhouse effect. Respected scientists differ on many of these questions in much the same way as they used to differ about composition and action of the solar system; however, we are attempting to resolve these difference through our ongoing studies.

The Department of Commerce, like the rest of the Federal government, has had to make difficult choices over the past few years. We have to keep Federal spending down. Recognizing the

importance of a coordinated effort to understand and predict climate variability and its impact on society, we have made every effort to provide the necessary resources for scientific research in this area. NOAA is responsible for monitoring the state of the atmosphere, including temperatures and key gases which are known to affect air quality and climate, conducting research to understand the processes that determine climate, and establishing the baseline for natural climate variability in order to improve our ability to predict the nature and effect of climate change. NOAA's research is directed towards determining the sensitivity of climate to man-made and natural disturbances and the impact of possible climate changes on global society.

The earth's climate, that is, the average state of the weather, responds to three factors: (a) external forces, such as changes in solar activity, both short-term and long-term; (b) internal interactions between the ocean and the atmosphere; and (c) changes caused by man's activities, particularly since the industrial revolution, such as the addition of chemically and radiatively active gases in the atmosphere. We do not know which of these factors is most influential in causing recent changes in our global climate.

Our climate depends critically on how much of the sun's radiation reaches the lower atmosphere and how much escapes back into space. Certain radiatively active gases can interfere with the ability of the these energy streamr to escape back into space. The result can be a global warming of the atmosphere, which is known colloquially as the "greenhouse effect." This effect is the same as that which causes your parked car to heat up -- solar heat gets in more easily than radiated heat gets out.

These radiatively active gases (which also are called "greenhouse gases") are produced both naturally and by human activities. Of the greenhouse gases that occur naturally (without the effects of human beings and the industrial revolution), carbon dioxide (CO2), ozone and water vapor are the most dominant. Human activities, however, do influence the concentrations of these gases and also add a few more gases that contribute to the "greenhouse effect;" notably, the freons used as refrigerants in air conditioning and cooling equipment, as air propellants in spray cans, and in many industrial processes; and methane (which is the gas used to heat our homes).

There is a generally accepted view, based on over twenty-five years of data on atmospheric carbon dioxide concentrations from observations by NOAA laboratories and from our knowledge of the physics of the atmosphere, that the net effect of human activities will be to produce, over the next half century, a global warming of the lower atmosphere by about two to four degrees, with a much greater cooling of the stratosphere. A climate change of this magnitude could have far reaching global effects on society. For example, the global warming of the early 1900's that resulted in the "Dust Bowl," amounted to only about half a degree centigrade. This is one example of localized and short-term changes, such as the increase in the level of the Great Salt Lake and changes in the levels of some of the Great Lakes. While of significant local importance, they are not of global scale. However, they could be the result of some basic global change, such as the El Nino.

Projections of future climate, however, should be made cautiously and should take into account two important caveats. First, while experiments project an average global warming due to increased carbon dioxide, no direct climate change due to increasing carbon dioxide has been confirmed. Other unknown factors can affect climate variability, which can be cyclical with differing frequencies of occurence and time durations. For example, the most significant global climate event for the past several years was the extreme 1982-1983 El Nino, an unusual warming of the eastern and central equatorial Pacific with accompanying shifts in the large-scale rainfall patterns of the region. The El Nino and the associated atmospheric Southern Oscillation, which is due to changes in the winds over the ocean which drive the ocean currents, can produce anomalies in many other regions of the globe as well. This event of 1982-1983 stimulated extensive studies and the development of observational programs to improve understanding and monitoring of large-scale atmospheric and oceanic phenomena. The United States took the lead in initiating a major international research program known as the Tropical Ocean Global Atmosphere (TOGA) in the Pacific Ocean, which began in January 1985. NOAA continues to lead U.S. participation in this program.

Further, this century showed global warming until about 1940, and then cooling until the 1970's. Within the last eight years, there again has been a warming of the global climate, but we do not know if this warming trend will continue. I am attaching a chart indicating surface temperature trends from since 1850 as Addendum A to my testimony. Just fifteen years ago, respected voices in the scientific community warned of the possibility of another ice age. Today, there is a great deal of concern about global warming. In short, we need to know more about the variability of our climate in order to anticipate future changes.

Second, we have very limited understanding of the possible feedback effects in the global climate system, that is, factors that can reinforce or counteract certain influences from outside the earth, particularly the sun. For example, during October of every year since the late 1970's, scientists have observed an astonishing reduction, reaching last year to 40%, in the ozone over Antarctica. The ozone level then recovers over a period of a several weeks. Several hypotheses have been proposed to account for the observed depletion. It could be a natural response to solar variations or it could be a direct response to man's activities. One hypothesis relating to anthropogenic effects (which are essentially man-generated) is that the depletion could be caused by freon pollution. If this hypothesis is correct, the chemical reaction which is theorized to result in the ozone depletion may be dependent on very cold temperatures in the stratosphere (which would be colder over Antarctica), which might be reinforced and enhanced by greater carbon dioxide levels in the upper atmosphere. This illustrates a possible feedback effect of carbon dioxide that was totally unexpected. During the coming months, NOAA will join with the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) in an expedition to Antarctica to investigate this chemical hypothesis.

The National Oceanic and Atmospheric Administration is playing an active role in the study of these and other questions relating to climate. One of NOAA's missions is to predict climate, and to predict we must observe and understand the effect of carbon dioxide and ozone as well as other greenhouse gases on the global climate.

In carrying out this mission, NOAA provides long-term monitoring of atmospheric chemical constituents. NOAA continuously monitors greenhouse gases at four laboratories located roughly from Pole to Pole: Point Barrow, Alaska; Mauna Loa, Hawaii; American Samoa; and the South Pole. NOAA collects air samples from throughout the atmosphere from these locations as well as from about 20 other primary locations. They take samples and measurements primarily at the earth's surface. These laboratories are located in unpopulated areas because data used to establish the baselines for climate variability must be collected in areas that are not affected by human activity. NOAA then analyzes the data to understand changes in volume and composition of these gases, to identify their sources, and to understand how they are removed from the lower atmosphere.

In addition, in order to understand the dynamics of global climate, NOAA scientists simulate its behavior with mathematical models. For example, at the NOAA Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, a model is used to conduct various types of experiments based on past and present global climate data as well as future projections in an effort to improve our ability to predict the possible impact of increased carbon dioxide or trace gases on the climate.

The level of the sea also may be an indicator of global warming. Sea level has risen about 100 meters since the end of the last ice age (about 15,000 years ago). Until recently, interannual and longer term sea level fluctuations could not be easily distinguished from vertical land motion (subsidence or uplift), which made it difficult to estimate actual changes in mean sea level. Recent advances in geodetic techniques, including the global positioning system (GPS) and very long baseline interferometry (VLBI), now make it possible to measure exactly and discriminate between real changes of absolute sea level and apparent changes due to vertical land motion. NOAA is monitoring the sea level, in addition to atmospheric gases, in order to establish a baseline of natural variability.

NOAA also gathers and analyzes data on global cloudiness. Under the International Satellite Cloud Climatology Program (ISCCP), measurements are collected from the five geostationary meterological satellites and the polar orbiting satellites to obtain a data set of global cloudiness in a format that is easily accessible for study. The United States, the European Space Agency, Japan, France and Canada are involved in this program.

NOAA also is monitoring and studying the sources and causes of ozone formation and depletion and the effect of ozone change on our climate. NOAA also monitors ozone and temperatures on a global scale from its operational weather satellites. Ozone is a greenhouse gas which is increasing in the lower atmosphere. Ozone is beneficial in filtering out ultraviolet rays, and its depletion in the stratosphere could result in an increase in skin cancer and other environmental consequences. Ozone changes in the stratosphere also will vary the temperature in the stratosphere. At this point, we are not fully certain what overall impact changes in atmospheric ozone would have on global climate.

In addition to NOAA's programs, the National Bureau of Standards (NBS) has developed standard reference materials for calibrating instruments that measure the concentration of important gases such as carbon dioxide, ozone, methane and some freons in the air. These primary carbon dioxide gas-in-air standards are necessary to ensure that an accurate, stable reference gas is available on a permanent basis for monitoring CO2 in the atmosphere.

Within the Federal government there is considerable excitement about pushing forward with research to monitor, understand and predict climate changes due to various greenhouse gases and the possible changes in stratospheric ozone. The National Climate Program Act of 1978 established a mechanism for interagency coordination within the Federal government. The National Climate Program Office (NCPO) within NOAA acts as the secretariat for the coordination of agency activities with the guidance of the National Climate Program Policy Board. The NCPO coordinates the interagency planning activities of 17 Federal agencies, including the Department of Energy (DOE), the Environmental Protection Agency (EPA), and NASA, to name a few, in order to avoid duplication of effort and ensure that key problems are addressed.

We are continuing to realize that our planetary life support system is dynamic, and that it depends on a wide variety of

natural balances which can be significantly affected by man's activities. As the global population and technological changes increase and become more complex and interdependent, it is critical that we understand how natural climate variability and the impact of man's activities on the climatic system affect our health and environment.

Mr. Chairman, I would be pleased to answer any questions you or the other Members of the Subcommittee may have.

STATEMENT OF

Dr. William R. Graham

Deputy Administrator

National Aeronautics and Space Administration

before the

Subcommittee on Environmental Pollution
Committee on the Environment and Public Works
United States Senate

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss the current research activities and the role of the National Aeronautics and Space Administration with respect to the issues of ozone modification and climate change. I have prepared a written statement for the record, which, with your permission I will summarize.

I will first describe for you in detail the current NASA atmospheric chemistry and climate research programs, and then outline the type of research program that NASA judges to be needed to address these and similar types of environmental issues in the coming decade. While I will describe the ozone and climate programs separately, we now recognize that the ozone and greenhouse warming issues are strongly coupled because changes in ozone are predicted to modify the Earth's climate, and because the same gases which are predicted to modify ozone are also predicted to produce a climate warming.

Several years ago, at the direction of Congress, NASA implemented a program of research, technology development, and monitoring of the Earth's upper atmosphere, with particular emphasis on the stratosphere where 90% of the Earth's ozone layer resides. In compliance with the Clean Air Act Amendments of 1977, Public Law 95-95, NASA biennially prepares an assessment report on the state of knowledge of the Earth's upper atmosphere, and on the content and progress of the NASA Upper Atmosphere Research Program (UARP). Since 1978 NASA has provided Congress with five assessment reports on the potential threat to atmospheric ozone from human activities. These assessments reflect the work of hundreds of atmospheric scientists and were produced after extensive discussion and analysis. The conclusions of the latest assessment report, titled "Present State of Knowledge of the Upper Atmosphere: An Assessment Report: Processes that control ozone and other climatically important trace gases," was transmitted to Congress in January of this year and was reviewed for you yesterday by Dr. Watson. The second part of the report which was also transmitted to Congress in January was titled "NASA Upper Atmosphere Research Program: Research Summaries 1984-1985."

The long-term objectives of the NASA Upper Atmosphere Research Program are to perform research to:

(a) understand the chemical, dynamical, and radiative processes that control the physical structure and chemical composition of the Earth's upper atmosphere, and

(b) accurately assess possible perturbations of the upper atmosphere caused by human activities. Specifically, of greatest urgency at present is an assessment of the combined effects of continued increases in the atmospheric concentrations of carbon monoxide (CO), carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), oxides of nitrogen (NOx), and halogen containing gases such as chlorofluorocarbons 11 and 12 (CFCl3 and CF2Cl2) and methylchloroform (CH3CCl3) on atmospheric ozone and the climate system.

As Dr. Watson indicated in his testimony yesterday, our knowledge of the key physical and chemical processes controlling the chemical composition and structure of the upper atmosphere has advanced significantly during the last few years. However, we must recognize that significant uncertainties in our knowledge still remain and need to be resolved by a vigorous program of research. NASA is committed to continuing its leadership role in studying the upper atmosphere and working closely with the university and non-university scientific community; other U.S. government agencies, in particular the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the Environmental Protection Agency (EPA), and the Federal Aviation Administration (FAA); industry, i.e. the Chemical Manufacturers Association (CMA); and other national and international scientific agencies, e.g. the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), to resolve these outstanding uncertainties in an expeditious manner. NASA's unique role in studying atmospheric ozone is its satellite remote sensing capabilities in conjunction with its modelling and computational capabilities.

NASA's program is broad and comprehensive and its research activities generally fall into three broad categories:

(1) **Field Measurements and Technology Development:**

This activity consists of studying the geographic distributions and strengths of trace gases released at the Earth's surface, measuring the solar irradiance incident on the Earth's atmosphere, determining the chemical composition and physical structure of the atmosphere using a balanced set of in-situ and remote sensing techniques, and the development of instrumentation. A wide range of instruments are currently being utilized on a variety of platforms including aircraft, balloons, rockets, space shuttle, and satellites. Ground-based observations are also performed. The principal objective of the field measurements program is to provide a description of the composition and structure of the atmosphere which can be used as a test of the theoretical models. These field and satellite programs will overcome our greatest shortcoming which is that we are presently data limited. The most important recent development in our knowledge of the chemical composition and structure of the stratosphere has been the analysis validation and release of data obtained by instruments flown on the Nimbus 7 (the Limb Infrared Monitor of the Stratosphere (LIMS), the Stratospheric and Mesospheric Sounder (SAMS), and the Solar Backscatter Ultraviolet/Total Ozone Monitoring System (SBUV/TOMS)), Applications Explorer II (AEM-2) (the Stratospheric Aerosol and Gas Experiment (SAGE), and Solar Mesospheric Explorer (SME) (visible and infrared spectrometers) satellites, and on the Space shuttle (the high resolution ATMOS infrared interferometer). This data is currently undergoing further intensive interpretation.

(2) Laboratory Studies:

Laboratory measurements are carried out to provide the basic input data for the theoretical models. These data consist primarily of chemical kinetics rate constants and photochemical cross-sections. In addition, spectroscopic data of atmospheric constituents are acquired for the interpretation of atmospheric measurements. Development of calibration standards is also a vital aspect of this program.

(3) Theoretical Studies and Data Analysis:

The two principal activities in this area of the program are the development of a hierarchy of models to describe the chemical, radiative, and dynamical processes which control the chemical composition and physical structure of the present atmosphere and to predict possible future changes, and the analysis and interpretation of large satellite data sets and other major field measurement campaigns.

Some specific thrusts in the near term include:

(1) A vigorous effort to understand the processes responsible for the recent decrease in the ozone column above the Antarctic in spring-time. This effort is strongly supported by the NSF Polar program, NOAA, and by the CMA. International cooperation and coordination is anticipated. A campaign of ground-based field measurements, in conjunction with satellite observations, is already planned for this year, and preliminary planning for an aircraft and ground-based field measurement campaign for next year is already in progress.

(2) The final design and initial implementation of "An Early Detection of Change System." This system is being designed to provide the earliest possible detection of changes in the chemical composition and physical structure of the stratosphere, and the means to understand them. Successful implementation of this system will require cooperation and coordination at both the national and international level. Discussions on the implementation of this system are currently in progress.

(3) The Upper Atmospheric Research Satellite (UARS), for which the launch date is uncertain due to Challenger manifest changes, will provide the first simultaneous measurements of the atmospheric distributions of oxygen, hydrogen, nitrogen, and chlorine species, coupled with measurements of temperature, dynamical quantities such as winds, and energy inputs and losses. These measurements will allow us to study the coupling between the chemical, radiative, and dynamical processes which control the chemical composition and structure of the stratosphere, and, in particular, the amount and distribution of ozone, in a manner never before possible, the mechanisms responsible for atmospheric variability, and the response of the stratosphere to changes in external factors such as solar activity and natural phenomena such as volcanic eruptions.

(4) Atmospheric concentration measurements and flux measurements of biogenic gases predicted to control atmospheric ozone from representative ecosystems in order to understand past and future trends in the composition of the atmosphere.

(5) The continued development of theoretical models which can simulate the coupling between the chemical, radiative, and dynamical processes that control the chemical composition and structure of the atmosphere.

(6) Understanding the basic chemical cycles in the troposphere, and predicting the response of these cycles to both natural and human-induced perturbations.

A key question that NASA believes needs to be answered is, what is the timeframe to reduce some of the current uncertainties in our scientific understanding? While this is a difficult question, it can best be answered by saying that progress in most areas will be steady and that many of the key uncertainties should be significantly reduced within a decade. NASA expects very significant progress on the issue of Antarctic ozone within a few years, but understanding the coupling between the chemical, radiative, and dynamical processes that control the chemical composition and structure of the atmosphere will require the UARS data before much more progress is made. If the "Early Detection of Change System" is implemented, then significant progress on detecting and
understanding the causes of changes in stratospheric composition should be expected within a decade. But a fuller understanding of the factors which control atmospheric ozone will require a new initiative in the Earth sciences because the ozone issue is not simply a problem of understanding the atmosphere, but requires an intimate knowledge of the oceans and land. This theme will be discussed later after a discussion of the climate program.

The long-term objective of the NASA Climate Research Program is to conduct research to improve our understanding of the radiation and dynamical processes which govern the climate system of the Earth and to observe the physical properties of the system which influences its change. The unique aspect of the NASA program is its use of space technology to address these objectives. The program includes research on: establishing the long term data base required for climate studies; analyzing the data base; developing models to diagnose and describe the climate system; and developing special observing capabilities to address problems unique to climate.

Understanding the basic nature of solar and Earth radiation and its transfer through the atmosphere to and from the land surfaces and oceans is one of the fundamental goals of climate research. Monitoring and analysis of the sun and components of the Earth's radiation budget and their effects on the atmosphere, land and oceans are crucial to developing this understanding. They will be used to diagnose the present (and near future) state of the climate, for the formulation of empirical prediction techniques and, ultimately, for the development and validation of global and regional climate prediction models. Insights gained in studying the Earth's radiation budget are also vital to developing confidence in prediction of the long-term effects of man's influences such as CO_2, ozone, and aerosols, as well as the effects of natural phenomena such as volcanic eruptions.

Recognizing the importance of this research in improving our understanding of the mechanisms controlling climate variations, the National Climate Program has established a principal thrust in Solar and Earth Radiation and has assigned NASA lead agency responsibilities for organizing and conducting a long-term broad-based research program of observations and analysis. The broad nature of this activity has required close coordination with other federal agencies having overlapping programmatic interests, in particular NSF, NOAA, and DOE, as well as with the international scientific community through the World Climate Research Program.

Recent precise measurements from the NASA Solar Maximum Mission (SMM) and the Nimbus-7 Earth Radiation Budget (ERB) experiment have established that the total solar radiation flux, also known as the "solar constant," above the atmosphere is indeed variable. Since 1979, sensors on both spacecraft independently observed variations of the solar flux as large as 0.25 percent on time scales from days to weeks. The amplitude of observed monthly and yearly variations, although smaller, nevertheless have the potential for affecting climate and, as such, are high priority monitoring objectives. Additional data are now becoming available from the NASA Earth Radiation Budget Experiment (ERBE), which also confirm the observed solar flux variability. Future plans are to incorporate a similar instrument on the Upper Atmospheric Research Satellite (UARS), which will continue these measurements into the 1990's. Periodic Shuttle sortie flights are planned to verify the performance of the free-flyer measurements and to intercompare other instrument designs.

The study of the role of clouds in climate has been given a particular emphasis in NASA-sponsored climate research. Clouds have a very strong modulating influence on the radiative energy exchange between the atmosphere and the upper and lower boundaries. They control the amount of solar energy absorbed by the climate system as well as the longwave energy radiated to space. The partitioning of the solar energy input between the atmosphere and oceans is also highly dependent upon cloud cover. These effects are extremely important on climate time scales and are critical to our understanding the effects of long-term CO_2 building in the atmosphere.

The first step necessary in understanding the role of clouds is to develop a climatology of the important cloud parameters over a period which reveals the diurnal, seasonal, and interannual variations. This requirement is being met through NASA's central role in the International Satellite Cloud Climatology Project (ISCCP), organized as a part of the World Climate Research Program (WCRP). The ISCCP, which began in 1983, routinely collects and processes cloud image data from the international array of operational meteorological satellites operated by the U.S., Japan, India, and the European Space Agency, to produce a five-year global cloud data set.

It is also essential to develop cloud models which incorporate the basic physical processes which contribute to the generation, maintenance and dissipation of clouds. In order to gather the data to test these cloud models, NASA, along with NSF, NOAA, and DOE, is conducting a series of field experiments in which the relevant atmospheric and cloud parameters will be measured in detail over a number of cloud formation cycles and a variety of synoptic weather conditions leading to the generation of various cloud types. This effort is a part of the First ISCCP Regional Experiment (FIRE) which began earlier this year and will continue through 1989.

Whether viewed as part of the WCRP, or as basic elements for the proposed International Geosphere/Biosphere Programs, these experiments will not only benefit oceanography and climate, but will also make fundamental contributions to Earth Science. In addition, the understanding gained from these experiments will assist in the design of future operationally oriented ocean and climate observing systems.

Two recent events have emphasized the ocean's importance in global climate: the disastrous 1982-1983 El Nino, which caused billions of dollars in damage and considerable loss of life, and the potentially harmful effects of increasing CO_2 levels in the atmosphere due to the burning of fossil fuels. We now know that our ability to understand and ultimately predict the droughts and flooding associated with a severe El Nino or with the warming predicted from a CO_2 increase is severely limited by a lack of ocean measurements. New global information available from satellites, coupled with data from the interior of the ocean, will meet this need. A second limitation is the lack of data on the distribution of global cloudiness. An ongoing international research project will address this deficiency.

Reports from the National Academy of Sciences and studies by various government agencies all point to the serious consequences of a global warming. They also stress the need for better understanding of the problem, particularly the role of oceans and ice cover in either modulating or amplifying the warming trend. The existing climate models used for predicting carbon dioxide induced warming oversimplify interactions between the atmosphere and the ocean. Any significant improvement will require many more observations leading to a better understanding of oceanic and atmospheric behavior.

For the oceans, the crucial measurements include ocean circulation, sea surface winds and temperatures, biological productivity, and the polar ice cover. Biological productivity can be determined through measurements of ocean color, which depends primarily on the photosynthetic pigments (chlorophyll) contained in marine plants. Since these plants are the basis of the marine food web, measurements of their amount and distribution are critical to obtaining a better understanding of biological and chemical processes, including the cycling of carbon through the oceanic ecosystems.

All of these measurements should be well distributed over the globe and made regularly to determine natural variability. Such coverage can be provided only from a space-based program operating over a period of several years.

NASA plans for the decade of the 1990's include the flight of a scatterometer (for sea surface winds) aboard the Navy Remote Ocean Sensing System (NROSS) satellite; a dedicated altimeter mission for ocean currents, the Ocean Topography Experiment (TOPEX), and a color scanner (for ocean biological productivity) aboard a platform of opportunity. In order to exploit the potential offered by this next generation of oceanographic sensors, we are working with the NSF, U.S. Navy, and NOAA, as well as with our international partners to plan a set of comprehensive at-sea experiments. Two examples are the Tropical Ocean Global Atmosphere and World Ocean Circulation Experiments being organized under the World Climate Research Program (WCRP).

It is well known that climate fluctuations and trends may have effects on society--on a regional as well as on a global scale. Land observations from satellites will also become part of a data base for monitoring changes of the surface, for instance of vegetation and snow cover, and of the climate of the surface of the earth. Such monitoring is particularly urgent at the present time due to man's increasing sensitivity to climatic fluctuations and the possibility that man's activities may have climatic consequences.

As stated earlier, the continued burning of fossil fuels may lead to increases in atmospheric carbon dioxide large enough to have a significant global climate impact. Changes in agricultural practices may lead to regional desertification or deforestation, which can lead to regional changes in the energy and moisture budgets. Draining wetlands can cause large changes in methane production, another important gas related to global temperature changes. It is clear that global, continuous monitoring of such anthropogenically induced changes, as well as naturally occurring variations, can only be obtained from satellites.

NASA is encouraging the development of the international satellite land surface climatology project to develop methodologies for deriving quantitative information concerning land surface climatological variables from satellite observations of radiation reflected and emitted by the earth. Such quantitative information is required to:

1) Monitor global scale change of the land surface caused by climatic variations or by human activity;

2) Further develop mathematical models designed to predict or simulate climate at various time scales;

3) Permit inclusion of land surface climatological variables in diagnostic and empirical studies of climate variations.

The time is appropriate for conducting such studies because of the increasing sophistication both of remotely sensed observations from space and the development of improved climate and medium range weather prediction models.

The land surface variables of interest and potentially obtainable more or less directly from satellite observations are vegetation cover, albedo, solar radiation, longwave radiation, skin temperatures, emissivity, soil moisture, and snow cover and depth. The work may be divided into two parts in present research.

1) Evaluation of existing satellite data collected in the last fifteen years to determine their usefulness in detecting climate related fluctuations or man-induced changes in the surface of the Earth.

2) Development and validation of methods to convert satellite-observed radiances to surface climatological variables. The validation effort will require intercomparison of satellite-derived quantities with simultaneous ground- and aircraft-based measurements, to be carried out in field programs in selected areas.

The first investigators in the first part of this work, retrospective studies, were selected in response to a letter issued in January 1985. The first field experiment will be held during 1987 at the Konza Prairie Grassland in Kansas. This site is managed by Kansas State University in conjunction with the National Science Foundation. It is anticipated that a letter inviting participation in this experiment will be isued by NASA in June 1986.

An experiment with somewhat similar aims is being conducted in France in the summer of 1986 under the auspices of the World Climate Research Program. NASA is sending a C-130 aircraft equipped with various radiometers for remote sensing for a six week period during this experiment. NASA has also assembled a team of investigators from NASA, USDA, and various universities to analyze the resultant data.

The land surface climatology work being led by NASA should lead to important new insights as to the interactions between the land and the atmosphere, and thus of how the Earth functions as a global system.

I would now like to describe to you the type of research program that NASA judges to be required to improve our scientific understanding of a number of environmental issues that affect not only the United States but also the whole world. It is evident that the Earth is a planet characterized by change and has entered an era when the human race has achieved the ability to alter its environment on a global scale. The ozone and greenhouse warming issues which have been discussed during these hearings are just two of the interrelated environmental issues we face today.

To gain a scientific understanding of how human activities will affect the Earth's environment requires a new approach to Earth sciences. The scientific community believes that we need to obtain a scientific understanding of the entire earth system on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to change on all time scales. In particular, the immediate challenge is to develop the capability to predict those changes that will occur in the next decade to century, both naturally and in response to human activity. This will require a nationally and internationally coordinated program of interdisciplinary research to investigate long-term, (10-100 years), coupled physical, chemical, and biological changes in the Earth's environment recognizing that land, atmospheric, oceanic, and biospheric processes are strongly coupled on a variety of temporal and spatial scales. Such a research program is absolutely necessary for informed policy decisions.

The National Academy of Sciences/National Research Council (NAS/NRC) and the International Council of Scientific Unions (ICSU) are currently formulating such a research program. Their programs are known as the Global Change or the International Geosphere Biosphere Program (IGBP). This program would build upon the many excellent ongoing national and international research programs in Earth sciences and would not duplicate or replace them. In parallel, NASA has developed a Global Habitability program whose goals and objectives are totally consistent with these proposed programs. NASA is ready to cooperate fully in the detailed scientific planning of such a program in conjunction with the scientific community through the NAS/NRC and ICSU, and implementing the U.S. component of this program with the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the Department of Energy (DOE), and other government agencies. The studies of the Earth System Sciences Committee (ESSC), which was established in 1983 by the Advisory Council of NASA, will provide NASA with a defined near-term program, and a definition of its specific role in Earth System Sciences.

INTERNATIONAL ASPECTS OF CLIMATE CHANGE AND OZONE MODIFICATION

Testimony of
Ambassador Richard Elliot Benedick
Deputy Assistant Secretary of State
for
Environment, Health and Natural Resources

Senate Committee on Environment and Public Works
Subcommittee on Environmental Pollution

June 11, 1986

I. CLIMATE CHANGE

International interest in the prospect of global warming and attendant climate changes has risen significantly during the past year. The Department of State and other U.S. agencies are working on this complex, multi-disciplinary subject in various bilateral and multilateral fora. (See attached list of 1986 meetings related to this subject.) Most of this activity concerns the state of scientific knowledge and how to improve it. There is also, however, a growing sense that governments and regional organizations need to consider when policies to reduce the potential for anthropogenic climate change may be appropriate, even with remaining uncertainties about the magnitude and timing of global warming.

Background

There is general agreement in the world scientific community that there has been occurring a significant buildup of carbon dioxide (CO_2), as well as other anthropogenic non-CO_2 trace gases, most notably nitrogen oxide, ozone, and the chlorofluorocarbons, which have the effect of absorbing long-wave radiation in the atmosphere and thereby raising the planet's temperatures. These trace gases are a recently discovered dimension to the problem, with combined effects which may equal those of CO_2. The continuing increase of all these "greenhouse" gases is likely to be the most important cause of climate change over the next century.

There is growing realization that factors contributing to global climate change are interrelated. For example, methane in the atmosphere is increasing partly because of rice paddies, cow dung, and termites; certain microbes in the ocean release a sulfur-containing gas; destruction of forests releases CO_2; man-made emissions of sulfur dioxide and nitrogen oxides are chemically transformed in the atmosphere into acid precipitation; and chlorofluorocarbons from industrial sources contribute not only to global warming but also to depletion of the ozone layer.

Villach Conference

A scientific conference took place in October 1985, at Villach, Austria, under the auspices of the United Nations Environment Program (UNEP), the World Meteorological Organization (WMO), and the International Council of Scientific Unions (ICSU). The meeting resulted in a statement that summarized the latest scientific findings on this subject. The major conclusion was that carbon dioxide and other greenhouse gases appear to be accumulating in the atmosphere at concentrations that could cause, by the first half of the next century, a rise in global mean temperature greater than any in man's history. The Conference also concluded that, while some warming appears inevitable, the rate and degree of future climate change could be "profoundly affected by governmental policies on energy conservation," use of fossil fuels, and the emission of some greenhouse gases."

The conference recommendations included a call to governments and regional organizations to take the results of the Villach assessment into account in designing future economic, industrial, and environmental policies. The recommendations also urged greater research and monitoring, including improved modelling, to reduce existent uncertainties in the projections. The conference further recommended analysis of policy and economic options for preventing, or adapting to, climate change, as well as efforts to increase public awareness of global climate issues. Finally, it was recommended that UNEP, WMO, and ICSU establish a small task force to monitor the Villach recommendations, to ensure periodic assessments of the state of scientific understanding and its practical implications, and to provide advice on further mechanisms and actions required at national or international levels, including consideration of a global convention.

Forthcoming International Meetings

In a follow-up to the Villach Conference, UNEP, WMO, and ICSU have organized a meeting of seven experts in Geneva, July 1-3, 1986, to discuss how to implement the recommendations. In addition, the International Institute of Applied Systems Analysis (IIASA) has organized a task force meeting of scientific experts at Laxenburg, Austria from June 30 to July 3. According to UNEP, the meeting will assess economic and policy options for preventing or responding to climate change. In June 1986, EPA, in cooperation with UNEP, will sponsor an International Conference on Health and Environmental Effects of Ozone Modification and Climate Change.

World Climate Research Program (WCRP)

International research on certain aspects of climate is currently coordinated through the WCRP, which is one of four components of the World Climate Program that was adopted in 1979 by the WMO, in cooperation with UNEP, ICSU, and other specialized agencies of the United Nations. (Domestic U.S. research is undertaken by several agencies, coordinated through the National Climate Program Office, established by P.L. 95-367, the National Climate Program Act of 1978.)

The major objectives of the WCRP are to determine the extent to which climate can be predicted and the extent of man's influence on climate. Therefore, one of the areas of interest of the WCRP is understanding the "greenhouse effect." The United States has played a leading role in the WCRP. International agreement has been reached on an overall scientific plan to carry out the necessary research.

Participating countries reviewed and coordinated their intentions to implement this far-reaching program at a May 12-16 meeting in Geneva. There was widespread support among countries for the WCRP. Participants decided that future action should be concentrated on the development of specific subprograms under the WCRP, including the Tropical Oceans and Global Atmosphere (TOGA) program, in which the United States is heavily involved. The WMO Executive Council is establishing a TOGA board at its current meeting.

Coordination of U.S. International Policy

The State Department is working with other government agencies to coordinate the United States approach to this issue in various international fora. Supported by EPA and the Department of Energy, the State Department leads international negotiations on protecting the ozone layer, under the auspices of UNEP; and on transboundary air pollution, including sulfur dioxide and nitrogen oxides, under the Economic Commission for Europe (ECE). The United States has ratified the ECE's Convention on Long-Range Transboundary Air Pollution, and the UNEP Convention for the Protection of the Ozone Layer is currently before the Senate for ratification.

The State Department is also working with the U.S. Agency for International Development, the Treasury Department, and the Department of Agriculture, in worldwide efforts to protect tropical forests, involving the World Bank, the UN Food and Agriculture Organization, UNEP, and other organizations. In addition, the State Department represents the United States, with support from other agencies, on the OECD Environment Committee, which is considering plans for a future workshop on global climate issues.

The State Department chairs a sub-committee dealing with bilateral and multilateral cooperation of the Committee on International Science, Engineering, and Technology (CISET). At a meeting in April, the State-chaired group identified global climate change and ozone layer modification as major continuing topics for consideration. We anticipate that this group, in its consideration of international aspects of this issue, will work closely with the National Climate Program Policy Board, which is responsible for coordinating domestic U.S. research.

II. OZONE MODIFICATION

The potential depletion of the ozone layer in the stratosphere is a global problem that may have far-reaching effects on human health and biological life generally. Further, chlorofluorocarbons (CFCs) and other trace gases not only have the potential to modify the ozone layer, but also contribute to global warming. A major result of the international concern about ozone depletion was the negotiation of the Convention for the Protection of the Ozone Layer.

Ozone Convention

The Ozone Convention, negotiated under the auspices of the United Nations Environment Program (UNEP), is essentially an agreement to promote international monitoring, research, and exchange of data on CFCs and other chemicals that may affect the ozone layer. It also creates general obligations to protect the ozone layer and provides procedures for eventually adopting protocols to the convention, which could contain specific measures to control, limit, prevent, or reduce emissions of ozone-modifying substances--should such measures be deemed necessary.

The Convention is not in itself, however, a regulatory instrument. It was adopted and signed at a Diplomatic Conference in Vienna in March 1985. The United States and 25 other countries plus the European Economic Community have signed it. We expect that the necessary ratifications (20) will take place within the next two years and that the Convention will enter into force in 1987 or 1988. The Convention was transmitted to the United States Senate for advice and consent to ratification in September 1985.

Both the U.S. chemical industry and environmental organizations support the Convention because of its potential contribution to the development of better scientific data. Surely it is in everyone's interest that any possible regulatory measures be considered on the basis of sound scientific and economic information rather than emotion.

The United States is the leading contributor to world scientific knowledge on the ozone layer and the impacts of potential depletion. Therefore, it is in our interest to have the Convention come into force as soon as possible. The Senate Foreign Relations Committee has favorably recommended ratification, and we hope that the Senate will give its advice and consent to ratification this year.

Possible CFC Protocol

During 1984-85, negotiations took place under UNEP auspices to develop a CFC control protocol. In April 1983, Norway, Finland, and Sweden tabled a draft protocol for controlling all CFC uses. In October 1983, the United States voiced its support for the part of the Nordic proposal dealing with CFCs used as aerosol propellants. Eventually, the Nordics, along with Canada and Switzerland, joined us in supporting an international aerosol ban protocol.

On the other side of the debate, the nations of the European Economic Community--who represented the other major source of CFC production--were initially opposed to any further controls on CFCs. However, they eventually came out in support of a protocol--but like us, and not surprisingly, they supported one which mirrored what they already had in place: namely, a 30 percent reduction in aerosol use and a cap on future CFC production capacity.

During the debate on these two alternative control systems, we pointed out many of the problems with their approach, and they, in turn, noted many of the flaws in our approach. The result was total gridlock, and there was no possibility for agreement on a protocol text at the Vienna conference.

The Diplomatic Conference in March 1985 decided that a scientific and economic factfinding process should take place before negotiations on a CFC protocol resume in November 1986. That process includes three international scientific conferences on ozone modification; an international workshop, divided into two parts: demand and technical controls, and alternative controls strategies; and two domestic U.S. workshop sessions to prepare for the international meetings. (See attached list of meetings on this subject.)

Both U.S. industry and environmental groups are participating in the factfinding process. The United States Government has an open mind on whether a protocol is necessary and, if so, what controls are required. We hope that greater international consensus will develop as a result of this process.

According to the current timetable, negotiations on a protocol that begin in November may be completed during a diplomatic conference that is tentatively scheduled for April 1987. Protocol negotiations, however, may take longer. It is also conceivable that the major participating countries may decide that an international control protocol cannot (or should not) be achieved. I should stress that our minds are open as to what further steps, if any, might be taken under the Convention, pending further consideration of the scientific and economic studies currently in process. Any protocol eventually proposed would, moreover, not be binding on the United States unless we were formally to agree to be bound.

International Meetings on Global Warming, 1986

Meeting	Dates	Locations
WMO/ICSU: World Climate Research Program	May 12-16	Geneva
WMO Executive Council	June 2-13	Geneva
IIASA: Task Force Meeting	June 30-July 3	Laxenburg, Austria
UNEP/WMO/ICSU: Meeting of Seven Experts	July 1-3	Geneva

International Meetings on Ozone Modification, 1986-1987

Meeting	Dates	Location
1986		
UNEP: Coordinating Committee on the Ozone Layer (CCOL)	February 24-28	Nairobi
U.S. (EPA): Ozone Layer Domestic Workshop on Demand and Technical Controls	March 6-7	Washington, D.C.
UNEP: Ozone Layer Workshop on Demand and Technical Controls	May 26-30	Rome
UNEP and U.S. (EPA): International Conference on Health and Environmental Effects of Ozone Modification and Climate Change	June 16-20	Arlington, Va.
U.S. (EPA): Ozone Layer Domestic Workshop on Alternative Control Strategies	July 23-24	Washington, D.C.
UNEP: CCOL	August 25-29	The Hague ?
UNEP: Ozone Layer Workshop Alternative Control Strategies	September 8-12	Leesburg, Va
WMO: Commission on Atmospheric Sciences	October 6-7	Sofia, Bugaria

Meeting	**Dates**	**Location**
UNEP: Working Group Meeting on CFC Protocol	**November**	**Geneva**
1987		
UNEP: Working Group Meeting on CFC Protocol	**January or February**	**Geneva**
UNEP: Possible Diplomatic Conference	**April ?**	**Geneva ?**
UNEP: 14th Governing Council Meeting	**early June ?**	**Nairobi**

Statement of Alvin W. Trivelpiece

Director

Office of Energy Research

Department of Energy

before the

Subcommittee on Environmental Pollution

Committee on Environment and Public Works

United States Senate

June 11, 1986

Mr. Chairman and members of the Subcommittee, it is a pleasure to appear here today to discuss the Department of Energy's role in examining the "greenhouse effect."

STATE-OF-THE-ART REPORTS

The timing of your hearing is most fortunate because the DOE has just completed a three year study to describe the state-of-the-art concerning research and knowledge on this important topic. Your staff has received the four major volumes of this important study and will soon be receiving two companion volumes of supportive material.

These reports document what has been learned since the DOE was given the lead in 1978 to coordinate the nation's research on increasing carbon dioxide levels. They cover research conducted in this country by the DOE and other Federal agencies and the significant research carried out by the international scientific community. The four state-of-the-art reports, called SOAs, cover the atmospheric carbon cycle, projecting the climatic effects, detecting the climatic effects, and direct effects on vegetation of the CO_2 increase. The two companion volumes describe information required for studies of the effects of CO_2 and climate change on renewable resources and human health, and on glaciers, ice sheets and sea level. These documents provide the latest word about what is known, unknown and uncertain about the CO_2 issue and they describe current data and modeling capabilities. They outline potential avenues of research for reducing critical unknowns and uncertainties.

More than 70 scientists from five nations have participated in the preparation of the 39 chapters contained in these volumes. In addition, each chapter and each complete SOA volume has gone through extensive peer review by the American Association for the Advancement of Science, an effort which involved nearly 300 international scientists. This has been a substantial effort with significant results.

FINDINGS

I will briefly describe some of the major findings contained in the reports. First, the concentration of atmospheric CO_2 continues to increase at about 1.5 parts per million per year, a rate that has been sustained for the past decade. Over the past century the CO_2 level has increased 25 percent. This is a non-trivial change of an important constituent of the earth's atmosphere.

With regard to the future, atmospheric CO_2 changes are uncertain and will depend mainly on the rate of growth in energy demand and on the energy supply systems that are used by the developed and developing world. There is no doubt that future economies will require more energy; the main uncertainty is how much and what kind. Rapid economic growth rates and high fossil energy usage could increase CO_2 emissions so that atmospheric CO_2 concentrations that existed in the 19th century could be doubled by the middle of the 21st century; slower growth rates and smaller demands would obviously defer a doubling to a time beyond that.

One of the first questions investigated when DOE initiated research on the CO_2 problem was the contribution of CO_2 to the atmosphere from disturbances of the terrestrial biosphere. The SOA report on "Atmospheric Carbon Dioxide and the Global Carbon Cycle" points out that CO_2 from energy emissions is the main factor responsible for the rise of atmospheric CO_2. New data, better analysis, and improved models now estimate that CO_2 generated by deforestation and from conversion of land to agriculture is presently on the order of 20 percent of that produced from burning fossil fuel. This estimate is down considerably from initial estimates of several times larger than that from fossil fuel; the large biospheric estimates proposed about one decade ago simply have not been confirmed according to improved data and analyses of the SOA. This refinement means that one major source of uncertainty about the global carbon system has been reduced. Biospheric carbon is no longer a major source of uncertainty in estimates of future atmospheric CO_2.

One central question is "how has the climate responded to the 25 percent increase of CO_2?" The best answer is we don't know. Elementary theory and simple physics suggest increased CO_2 would alter the earth's radiation balance (incoming versus outgoing radiation) and thus cause a warming. However, the Earth's climate system is complex and cannot be represented with simple models. The existence of a number of factors that could change climate confounds attempts to evaluate a single cause like increased CO_2 levels. Long-term temperature data show a trend towards warming, but thus far neither global hemispheric, nor regional changes satisfy statistical significance.

Another key question is "how reliable are predictions from global climate models?" The SOA report on "Projecting the Climatic Effects of Increasing Carbon Dioxide" concludes that different models are in general agreement about change of average global temperature; that is, they would predict a global average temperature rise of 1.5 to 4.5 degrees Celsius for an increase in CO_2

from 300 to 600 parts per million. The model results are in agreement with the general theory of global warming. However, there is considerable uncertainty with model projections of regional temperature change and with regional patterns of rainfall. The regional climate predictions often do not agree with actual regional climate for today's CO_2 conditions, and the model predictions are simply inconsistent with each other. Such unreliability is good reason for not using model output to estimate regional change of temperature and precipitation. The models are the best available research tools for investigating the global climate system, but such climate model predictions are not yet suitable for impact studies and governmental decisions on CO_2, climate change and energy policy.

There is often more than one facet to every issue; that is, there are positives, negatives and neutrals. The CO_2 problem is no different. For example, one part of our environment could benefit from more CO_2. Plants grow better with more CO_2. During the past five years, considerable attention has been devoted to this positive aspect of the CO_2 issue.

The SOA report on the "Direct Effects of Increasing CO_2 on Vegetation" summarizes data from outdoor experiments that confirm that growth and yield of most crops will increase if CO_2 doubles. Specifically, field data from about 10 new season-long experiments with food, forage and fiber crops provide convincing evidence that CO_2 enrichment causes greater growth and productivity. When grown at a CO_2 level twice today's atmospheric levels, five of six crops examined yielded 30% to 80% more harvestable product. In addition, the efficiency of plant water use tends to improve with more CO_2. To date plant scientists have generally thought that atmospheric CO_2 would remain constant. After recognizing that the CO_2 level is rising, and with more attention to direct plant effects of CO_2, some plant physiologists, agronomists and ecologists are examining the effect of such changes and the new opportunities in the future plant world they present. Other properties of crop and ecological systems will likely change, but it is not known what direction or how much. To answer such questions requires additional research.

The possibility of a substantial sea level rise is one of the concerns regarding the greenhouse effect. There is as yet no concrete evidence that sea levels in recent times have been affected by atmospheric CO_2 increases. However, the models predict that should CO_2 concentrations increase to twice the present CO_2 level, some coastal flooding would be inevitable. Various estimates of sea level rise remain relatively uncertain because of incompletely understood ocean physics and cryospheric (ice) relations. Sea level estimates that take full account of ice dynamics indicate the possibility of a half meter rise (two feet) by the year 2100 assuming that the present rate of increase of CO_2 continues unchecked. Such a sea level rise would produce problems for many coastal nations. However, we must remember that our present understanding is based upon limited models and data.

ACCOMPLISHMENTS

There have been several important accomplishments since the Federal government received a recommendation from the National Academy of Sciences in 1977, "To reduce uncertainties and to assess the seriousness of the matter, a well-coordinated program of research that is profoundly interdisciplinary in character, and strongly international in scope, will be required".[1] The Department of Energy has been responsive to this charge and I would like to review briefly some of the more important accomplishments and to illustrate this international flavor.

Recently, the detailed history of atmospheric CO_2 during the past two centuries was observed from air bubbles trapped in an ice core from Siple Station, Antarctica. Measurements of unprecedented time resolution from this ice core have made it possible for the first time to trace the increase of the atmospheric CO_2 over the two centuries before continuous detailed measurements began at Mauna Loa, Hawaii in 1958. The CO_2 content of the atmosphere has increased from about 280 parts per million (ppm) to 345 ppm, or about 25 percent. The information is important for calculations of the rate of change of the global carbon system, and for the climatic response to increasing CO_2. These ice core CO_2 measurements were performed on cores collected by scientists from the USA, Denmark and France, with actual measurements of CO_2 change by scientists from the University of Bern, Switzerland (see figure 1).

About one decade ago leading scientists concerned about the CO_2 issue prepared a number of recommendations which in large measure have now been implemented. One recommendation called for reliable CO_2 standards. Accurate and reliable measurements of atmospheric CO_2 depend on high-quality standards. I am pleased to report that the National Bureau of Standards has now prepared stable

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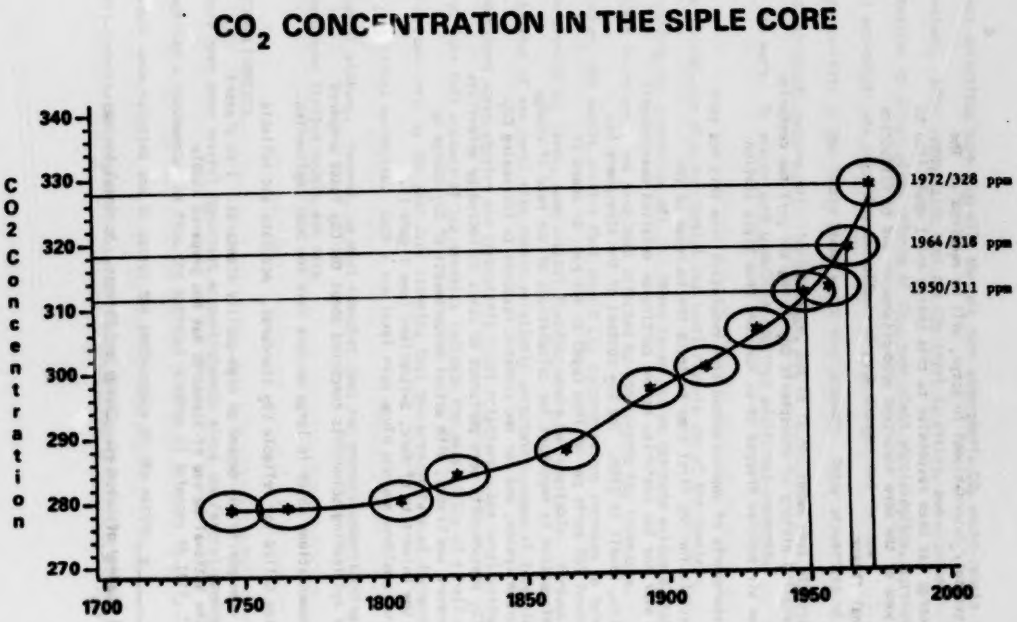
[1] National Academy of Sciences. Energy and Climate. National Academy Press; 1977, p. ix.



CO$_2$ CONCENTRATION IN THE SIPLE CORE

Figure 1. Measured mean CO$_2$ concentration plotted against the mean gas age, calibrated with the Mauna Loa record for the youngest gas age. The ellipse around each data point corresponds to the close-off time interval of 22 years and the CO$_2$ concentration measurement uncertainty (±3 ppm).

standards for use by the international CO_2 measurement community. Six standard reference gases have been prepared and certified.

The University of East Anglia in Britain and the University of Massachusetts have jointly developed a global temperature and precipitation data base to document climate change over the last 130 years. An analysis of the records suggest that the Northern Hemisphere's average surface air temperature has warmed by about 0.3-0.7°C over the last century. The most stable temperatures appear to have occurred in mid-latitude regions, while larger variations have occurred in the polar region, particularly during winters. However, the general warming trend has not been regionally coherent; for example, north central Canada and central Asia apparently were cooler during 1920-1940, a period generally of Northern Hemisphere warming. Despite the limitations of this data base, it remains the most complete set of temperature observations for land masses of the Northern Hemisphere.

THE INTERNATIONAL NATURE OF THE PROBLEM

One characteristic of the CO_2 question reemphasized by the SOA studies is the global nature of the problem. The regional trends in CO_2 emissions from global fossil fuel have been changing since 1950 due to changes in population, urbanization, industrialization and agricultural practice. For example, in 1950 when the total CO_2 concentration was 310 ppm, North America accounted for nearly 43 percent of the world's CO_2 emissions, Western Europe 23 percent and the centrally-planned nations of Eastern Europe 18 percent. In contrast, by 1980 when the total CO_2 concentration was 330 ppm, North America contributed only 27 percent of CO_2 emissions, Western Europe 16.5 percent, and the centrally-planned Eastern European nations 24 percent while the developing nations rose to over 12 percent from a 1950 contribution of less than 6 percent. In summary, CO_2 concentration in the atmosphere is a global issue and requires international cooperation on research to understand the problem and determine the possible cause and effect relationships.

INTERNATIONAL ACTIVITIES

The Department of Energy is concluding an agreement on a joint climate research program with the Peoples Republic of China (PRC). The objective is to use regional scale data to investigate the relationships between global climate as defined by models and local climate as defined by observations. The concept is joint research, fully utilizing each country's expertise such as unique facilities, model concepts and data resources. The project is conducted through the Chinese Academy of Sciences' Institutes of Geography and Atmospheric Physics.

More than 30 PRC scientists and graduate students will participate in this program. Some 20 USA scientists and graduate students from industry, universities and the DOE laboratories will be involved. The products will be improved data sets as well as new insights to regional climate and climate change. A long-term history of regional climate is being reconstructed for China through gazettes and memos to the emperors of China, journal notes, and a reexamination of archives of hundred year-old instrumental records. These data bases will not only provide data for models, but clues to causes of cyclic climate changes that either could enhance or mask greenhouse effects.

In addition to the work I described by the Swiss with the Siple ice core, by the University of East Anglia and the University of Massachusetts on the observed temperature change, by NBS in developing standard reference material for world-wide use, and joint research with China, the carbon dioxide research program conducts much more collaborative research involving international participation. A list of the participants is attached.

RESEARCH NEEDS

It is essential that a reasonable understanding of the cause and effect relationships between CO_2 concentrations and global warming or other phenomena exist before any energy policy recommendations are made that will influence future generations profoundly. The state-of-the-art reports indicate that substantial progress has been made in reaching this goal.

The major uncertainties about the connection between world energy use and the climate of our Earth have largely been identified. During this current fiscal year, the SOAs will be used to refine our research thrusts and priorities to ensure that these uncertainties are addressed. Our objective is to reduce these uncertainties to provide a factual basis for intelligent decision making. I will briefly outline some of the elements involved in reaching this objective.

First, in order to document how climate is changing and that the changes are consistent with model projections, continued monitoring of the climate is required. Further, the models must be compared to the observed data and to each other to understand where and why the models agree and disagree. The result of this research will improve climate models, and thus our ability to estimate regional climate change.

The models do not now provide reliable estimates of regional climate change (where a region may be a river basin or an agricultural belt). Research using computer models reveal that two major elements result in uncertainties that influence current estimates of magnitude and rate of climate change. They are oceans and clouds. Ocean transport of heat is a major determinant of regional climate. The oceans also store large quantities of heat, and thereby delay greenhouse warming. The present range of uncertainty for the delay is a decade to a century. It is necessary to understand how heat is transferred from the upper layer to the deep oceans to account for this lag and to account for the ocean's role in determining regional climate.

In addition to their role in the precipitation process, clouds are a major contributor in controlling the amount of sunlight that reaches the earth's surface and the amount of heat reradiated to space. Clearly, then, the way clouds are portrayed in climate models can add to or reduce predicted greenhouse warming. The current mathematical description of clouds in climate models is rudimentary. It remains to be determined how model clouds resemble real clouds throughout the cloud life cycle. A key task is to obtain data that can test such mathematical expressions, and account for observed precipitation patterns.

Additional attention will be devoted to studies of primary effects of CO_2 and climate change with biological systems. Our first objective is to establish the scientific and knowledge base required for evaluating system-level biological responses to future changes of climate and CO_2; this includes the development and validation of models for improved predictions. The emphasis is with changes of system-level properties such as productivity, function and structure (including composition changes), water use and plant-animal-microbial relationships. The focus is agricultural crops and the relatively unmanaged ecosystems.

Changing biological features of the earth's surface can alter properties of the atmosphere such as water vapor, albedo (the ratio of reflected radiation to incident radiation), the abundance of other trace gases, or the rate of CO_2 exchange with the atmosphere. These altered processes and properties affect the climate system and exert feedbacks on climate and climate model performance, and a second objective is to provide biological information needed for improving climate model sensitivity and predicting climate response to CO_2.

A third objective is to provide scientifically-based cause and effect information needed for resource analysis. Initially, this will include projections of change in system-level properties such as productivity and yield for use in analysis of food and fiber resources. Information about direction, rate and magnitude of changes of crops and ecosystems will thus provide the basis for evaluating effects on range, forest and water resources.

As previously stated, information on the carbon cycle, climate change and vegetation response is currently inadequate for determining the impacts of

CO_2-induced climate and vegetation changes. The research on characterizing information requirements for studies of CO_2 effects reveals that refinements are needed in research techniques and each of the fields examined (water resources, agriculture, fisheries, forests and human health) suffers from lack of pertinent data. Recognizing the fact that CO_2 increases must be evaluated as they pertain to quantifiable impacts on resources including energy, biological and physical systems, economic factors, and human institutions, it is now appropriate to use the information obtained from the SOAs to direct a focused program on the effects of increased atmospheric CO_2 levels on key resources. There is a need to define, from the perspective of resource impacts analysis, what information, models, and methods are needed from other CO_2 research components and resource areas to reduce the unknowns and uncertainties associated with the effects of rising CO_2 levels. It is necessary to rank research on the basis of its potential for evaluating the impacts on a given resource.

The Department of Energy strongly endorses the research programs being conducted under the auspices of other agencies. For example, the international Tropical Oceans and Global Atmosphere (TOGA) program (primary U.S. participation by NOAA, NSF and NASA) is an oceanographic program that will develop very important data for climate modeling activities. Likewise, the World Ocean Circulation Experiment (WOCE) (primary U.S. participation by NSF, NOAA and NASA), using both satellites and ships to develop data of the world's oceans, including tracer data on the circulation of the ocean waters, is a program to supply data which will be vital in the development of improved carbon cycle models as well as general circulation models. The International

Satellite Cloud Climatology (ISCC) program (primary U.S. participation by NASA), another internationally recognized and participating program, will begin to give us some of the necessary data on clouds, their formation and radiative properties, which we do not now have for integration into climate models to improve regional predictions.

Improved data, analysis and modeling stand as the key ingredients needed to develop the knowledge base required for decision making. In approximately a decade, with this type of support, we believe it will be possible to recommend policy options.

SUMMARY

The United States is one of the few nations that has committed itself to a goal-oriented research program to understand the extremely complex, global greenhouse effect. This commitment is easily illustrated by the fact that the U.S. has expended almost $150,000,000 from 1980 to 1986 on this issue. (Expenditures by year and U.S. government agency are listed on Table 1, Funding 1980 - 1986 of the National Program on Carbon Dioxide-Climate.) The issue is international; it is possible that effects might be more adverse than beneficial to future generations of every nation, and responses to the greenhouse effect also must be international.

There is a critical need to continue the U.S. research program, to affirm scientifically sound approaches and objectives, and to provide adequate resources for research. The existing knowledge base is considered inadequate for recommending changes in the nation's energy systems. Causes and effects of

Table 1. FUNDING 1980 - 1986 OF THE
NATIONAL PROGRAM ON CARBON DIOXIDE-CLIMATE
(In Thousands of Dollars)

	Actual						Estimate			Request
AGENCY	FY1980	FY1981	FY1982	FY1983	FY1984	FY1985	FY1986	TOTAL	PERCENT	FY1987
DOE	6024	9749	11971	9103	12427	13072	12586	74932	51	13580
NSF	6472	5517	4246	5543	5346	5114	5114	37352	26	
DOC/NOAA	2298	2185	2274	1961	1982	2700	2680	16080	11	
USDA/ARS	0	906	3113	2923	2665	1351	1351	12309	8	
DOI/USGS	475	596	156	207	275	215	215	2139	1	
NASA **	100	230	39	0	0	736	736	1841	1	
EPA	0	296	380	*	283	319	319	1597	1	
TOTAL	15369	19479	22179	19737	22978	23507	23001	146250	100	

* - DATA MISSING

** - WHILE NASA DOES NOT DIRECTLY SUPPORT CO2 RESEARCH, SEVERAL PROJECTS FROM THEIR CLIMATE RESEARCH PROGRAM FOR FY 1985 AND 1986 CONTRIBUTE SIGNIFICANTLY TO THE CO2 KNOWLEDGE BASE AND ARE ACKNOWLEDGED HERE FOR COMPLETENESS climate change are simply too poorly understood to warrant changes of energy policy. There is also an obligation to persuade other nations to pursue appropriate research on the greenhouse issue to complement U.S. efforts. It must be clearly understood that the U.S. contributes only slightly more than one-quarter of the total CO_2 emissions. Furthermore, the fraction contributed by the U.S. is decreasing as energy use by other countries increases. Therefore, even if scientific evidence warranted action, the U.S. could not by itself substantially reduce the rate of CO_2 buildup.

This concludes my prepared statement. I would be pleased to answer any questions.

A LISTING OF CO_2

CURRENT COLLABORATIVE RESEARCH
INVOLVING INTERNATIONAL PARTICIPATION

BY RESEARCH CATEGORY

- o CARBON CYCLE
- o VEGETATIVE RESPONSE
- o CLIMATE & CO_2
- o OTHER INTERNATIONAL ACTIVITIES

F. A. KOOMANOFF
DIRECTOR, CO_2 RESEARCH DIVISION
OFFICE OF BASIC ENERGY SCIENCES

(301) 353-3281
January 1986

CURRENT COLLABORATIVE RESEARCH INVOLVING INTERNATIONAL PARTICIPATION
CARBON CYCLE

U.S. Investigator/Affiliation	Research Title	Activity	International Investigator/Address
6. Minze Stuiver University of Washington	Geochemical Determination of Biospheric CO_2 Fluxes to the Atmosphere	Studying tree-ring $^{13}C/^{12}C$ ratios to determine the history of atmospheric CO_2.	Hans Oeschger Physikalisches Institut Universitat Bern Sidlerstrasse 5 CH-3012 Bern SWITZERLAND
7. George M. Woodwell Marine Biological Laboratory and C. J. Tucker National Aeronautics & Space Administration	Remote Sensing of Deforestation in the Amazon Basin	Studying deforestation and agriculture land use changes by means of NOAA-7 and LANDSAT data. Ground truth being done by Brazil.	P.M. Fearnside Ecology Department National Institute of Amazon Research Manaus, Brazil
8. H. Craig Scripps Institution of Oceanography	Argon-39 Measurements on Samples Extracted from Ocean Water	Determine abundance of ^{39}Ar from deep samples of N. Atlantic and N. Pacific.	Hans Oeschger Physikalisches Institut Universitat Bern Sidlerstrasse 5 CH-3012 Bern SWITZERLAND
9. Direct Contract	Reconstruction of History of Atmospheric CO_2 Content and the $^{13}C/^{12}C$ Ratio by Ice-Core Analysis	Determine time series of atmospheric CO_2 from measurements of CO_2 trapped in ice.	Hans Oeschger Physikalisches Institut Universitat Bern Sidlerstrasse 5 CH-3012 Bern SWITZERLAND
10. Taro Takahashi Lamont-Doherty Geological Observatory of Columbia University	Assessment of Carbon Dioxide sink/source in the Oceanic areas: Seasonal and Geographic Variability	Collect and analyze seasonal and regional variability of CO_2 chemistry in high latitude deep water formation in areas of North Pacific	Japan Lines Inc. M/V Japan Alliance container ship

CURRENT COLLABORATIVE RESEARCH INVOLVING INTERNATIONAL PARTICIPATION
CARBON CYCLE

	U.S. Investigator/Affiliation	Research Title	Activity	International Investigator/Address
11.	Berrien Moore III University of New Hampshire and Peter G. Brewer Woods Hole Oceanographic Institution	Ocean Models in the Global Carbon Cycle	Development of a model of the world oceans for quantitatively describing the oceanic uptake of CO_2 over the past 140 years, and fluxes of CO_2 both in the future and in the geologic past	Bert Bolin Department of Meteorology Arrhenius Laboratory University of Stockholm S-106 91 Stockholm SWEDEN
12.	W.M. Post Oak Ridge National Laboratory	Soil Carbon in the Global Carbon Cycle	Determining the changes in vegetation structure, establishment, composition, biomass, and soil nutrient status (particularly coil carbon density) of forest fallow land in southwest Nigeria	Barbara G. Herren International Institute of Tropical Agriculture PMB 5320, Oyo Road Ibadan NIGERIA
13.	W.M. Post Oak Ridge National Laboratory	Soil Carbon in the Global Carbon Cycle	Development of a chronosequence of recovery following slash-and-burn agriculture in the uper Rio Negro	Rafael Herrera Centro de Ecologica, Instituo Venezolano de Investigaciones Cientificas, Caracas 1010 VENEZUELA

CURRENT COLLABORATIVE RESEARCH INVOLVING INTERNATIONAL PARTICIPATION
VEGETATIVE RESPONSE

U.S. Investigator/Affiliation	Research Title	Activity	International Investigator/Address
1. Darrell West Oak Ridge National Laboratory	Detection of Forest Response to CO_2	Identify/quantify CO_2 fertilization effect in tree rings. Swiss scientists participate in technique development. Data analysis involves USA, Swiss, Canada researchers.	F. Kienast/O. Braker Swiss Institute of Forestry Research Birmensdorf, Switzerland M. O. Berry/M. L. Parker Atmospheric Environment Service Canadian Climate Service Downsview, Ontario, Canada
2. Boyd Strain Duke University	CO_2 Effects on Perennial Plants	Collaborative research on response to CO_2 of grass-clover mixtures and tree species	D. Overdieck Universitat Osnabruck Osnabruck FEDERAL REPUBLIC OF GERMANY
3. Boyd Strain Duke University	Facilitate Communication of CO_2 Effects Research to Scientists in the PRC	Translating Critical Reviews and Research Plan Documents into Chinese to Acclerate Communication with PRC Scientists	Y. Luo Langzau University Langzau Peoplus Republic of China
4. Walter Oechel San Diego State University	CO_2 Effects on native and introduced grass species	Treating plants in the phytotron chamberes to compare potential responses to CO_2 enrichemnt	Ann Larigaurde Monpelier, FRANCE

CURRENT COLLABORATIVE RESEARCH INVOLVING INTERNATIONAL PARTICIPATION
CLIMATE-CO_2

U.S. Investigator/Affiliation	Research Title	Activity	International Investigator/Address
1. Frederick M. Luther Lawrence Livermore National Laboratory	Cloud and Radiation Interactions and Climate	Some 40 radiative models are being compared from 11 countries.	Participants from U.S., France England, Germany, Italy, Sweden, USSR, Canada, Netherlands, Australia, Switzerland
2. Gerald Potter Lawrence Livermore National Laboratory Robert Cess, University of New York at StonyBrook W.-C. Wang Atmospheric & Environmental Research, Inc.	Model Intercomparison and Preparation of Long-Term Data Sets	Comparing General Circulation Models to understand differences and relating large scale climate to regional climate. Obtain Q.C. and analyze U.S. & PRC climate data sets.	T. C. Ye, Vice President Academia Sinica Atmospheric Physics and Geography Institutes Academia Sinica People's Republic of China
3. Michael Schlesinger Oregon State University	NATO Advanced Studies Institute on Climate Modeling	NATO class activity: Examining model dynamics comparing model results and ocean delay mechanisms to transfer latest science to young researchers.	Participants: 15 NATO countries; and China, Sweden & Australia
4. W. Lawrence Gates Oregon State University	Model-Data Comparison	Pilot study to examine how to compare and what to compare between model generated climate parameters and observed climate parameters.	B. D. Santer University of East Anglia Norwich NR4 7TJ UNITED KINGDOM
5. Michael C. MacCracken Lawrence Livermore National Laboratory	Climate Change: Data Analysis and Model Comparison	Participation in US-USSR Bilateral Agreement Working Group on Climate: analysis of the temperature record for evidence of climate change, evaluation and comparison of models	Workshops and visits involving USSR and US scientists
6. Raymond S. Bradley University of Massachusetts	Studies of Climatic variability during the period of Instrumental Records	Analysis of the 1850-1985 temperature and precipitation data for the Northern Hemisphere	T.M.L. Wigley et al. Climatic Research Unit University of East Anglia Norwich NR4 7TJ UNITED KINGDOM

CURRENT COLLABORATIVE RESEARCH INVOLVING INTERNATIONAL PARTICIPATION
CLIMATE CO_2

U.S. Investigator/Affiliation	Research Title	Activity	International Investigator/Address
7. Donald Wuebbles Lawrence Livermore National Laboratory (proposed)	Trace Gas budgets	Modeling of atmospheric chemistry and the effects of increasing trace gas concentration	J. Karol Main Geophysical Observatory Leningrad USSR
8. Direct contract	On the Geographical Patterns of Climate Change	Documenting temperature and precipitation data from 1900 to present.	T.M.L. Wigley Climatic Research Unit University of East Anglia Norwich NR4 7TJ UNITED KINGDOM

CURRENT COLLABORATIVE RESEARCH INVOLVING INTERNATIONAL PARTICIPATION
OTHER INTERNATIONAL ACTIVITIES

U.S. Investigator/Affiliation	Research Title	Activity	International Investigator/Address
1. Uwe Radok University of Colorado	Surging as a Potential Response of Ice Sheets to CO_2-Induced Changes in the Polar Environment	Quantitative assessment of changes for CO_2-triggered or spontaneous ice sheet surges leading to sea level changes.	W. F. Budd Meteorology Department University of Melbourne AUSTRALIA
2. Michael R. Riches Carbon Dioxide Research Division, BES	International Satellite Cloud Climatology	Support of global satellite cloud reference data base.	Working with International Council of Scientific Unions (through National Aeronautics & Space Administration)
3. Michael R. Riches Carbon Dioxide Research Division, Basic Energy Sciences	SNOWWATCH 85: Workshop on CO_2/Snow Interaction	Assess snow data and snow processes related to climate changes that may occur as a result of increased CO_2	International Association of Hydrological Science, CO_2 sponsor with NOAA & DOE; U.S., Canada, USSR, PRC, U.K., & Switzerland
4. Roger C. Dahlman Carbon Dioxide Research Division, BES	World Meteorological Organization Experts Workshop on Pre-industrial Levels of CO_2	Support and participation in estimating pre-industrial levels of CO_2 from ice cores, tree rings spectral measurements.	Participants from U.S., Switzerland, France, Australia
5. Michael P. Farrell Carbon Dioxide Information Center, Oak Ridge National Laboratory	International Directory of CO_2 Research Community and Newsletter, CDIC Communications	Directory indicates addresses, telephone and scientific areas of research and/or interest. Newsletter is distributed twice a year.	Directory and Newsletter address list contain 2594 names, - 764 are from 49 countries other than the U.S.
6. Michael P. Farrell Carbon Dioxide Information Center, Oak Ridge National Laboratory	Expert System Development/ Evaluation for detecting erroneous bibliographic information	An Expert System is being developed to aid in understanding and correcting errors in bibliographic data files	C. Todescini International AEC Vienna, Austria

CURRENT COLLABORATIVE RESEARCH INVOLVING INTERNATIONAL PARTICIPATION
OTHER INTERNATIONAL ACTIVITIES

	U.S. Investigator/Affiliation	Research Title	Activity	International Investigator/Address
7.	F. A. Koomanoff Carbon Dioxide Research Division, RES	o World Climate Program o Commission of European Communities o International Association of Meteorological and Atmospheric Physics o International Association for Physical Sciences of the Oceans o International Geosphere/Biosphere Program	Coordination/Support and participation of International Conferences and National Academy of Sciences planning activities	o Commission of European Communities o World Meteorological Organization o International Union of Geodesy and Geophysics o International Council of Scientific Unions
8.	Larry M. Blair Oak Ridge Associated Universities, Inc.	Review of CO_2 Research Staffing and Academic Support	Surveyed Foreign National Students in U.S. Universities as a source of labor supply	1983-84 Foreign Students Environments estimates at 24,455 (in schools with over 1000 Foreign students and receiving CO_2 research funds)
9.	A. F. Spilhaus, Jr. American Geophysical Union	Partial Support of the Joint Assembly IAMAP/IAPSO	Assess the scientific status of large-scale atmospheric and oceanic processes and their interactions	International Association of Meteorology and Atmospheric Physics International Association for the Physical Sciences of the Oceans (1200 scientists)

CURRENT COLLABORATIVE RESEARCH INVOLVING INTERNATIONAL PARTICIPATION
CARBON CYCLE

U.S. Investigator/Affiliation	Research Title	Activity	International Investigator/Address
1. Robert B. Bacastow Scripps Institution of Oceanography University of California	Development of a Three-dimensional Model of the Natural Carbon Cycle in the Ocean and its Perturbation by Anthropogenic CO_2	Incorporating the carbon cycle into a 3-D transport model of the ocean developed by the Germans.	Klaus Hasselmann Max-Planck-Institut fur Meteorologie Bundesstrabe 55 D2000 Hamburg 13 FEDERAL REPUBLIC OF GERMANY
2. Robert H. Byrne University of South Florida	The Role of Aragonite in the Marine Carbon Cycle	Participated in the February/March 1985 MARION-DUFRESNE Indian Ocean cruise to collect data on aragonite dissolution kinetics.	A. Poisson Centre National de la Recherche Scientifique (CNRS) Paris FRANCE
3. C.-T. Arthur Chen Oregon State University	On the Increase of Total CO_2 in the World Oceans	Participated in the July/August 1984 and February/March 1985 MARION-DUFRESNE Indian Ocean expedition to make measurements of carbonate data; will collect additional data during the July 1985 cruises. Other cruises planned.	A. Poisson Centre National de la Reche Scientifique (CNRS) Paris FRANCE
4. H. Gote Ostlund University of Miami	Indian Ocean Radiocarbon	Participated in the February/March 1985 MARION-DUFRESNE Indian Ocean expedition to collect and measure ^{14}C. Other cruises planned.	Lillian Merlivat Department de Physico-Chimie CEA-CENS B.P. No. 2 91191 Gif-Sur-Yvette Cedex FRANCE
5. John F. Richards Duke University	Land Use and Vegetation Changes in South and Southeast Asia, 1700-1980 AD	Compiling historical data on land use change for modeling future atmospheric CO_2 concentrations.	Om Prakash Delhi School of Economics University of Delhi Delhi 7 INDIA and Pradeep Mehendiratta Director of the American Institute of Indian Studies New Delhi INDIA

UNITED STATES SENATE

SUBCOMMITTEE ON ENVIRONMENTAL POLLUTION

HEARING - JUNE 11, 1986

Testimony of Theodore K. Rabb

A massive survey of research on climatic impacts, published last year, leaves its reader with disturbing news about the buildup of Carbon Dioxide in the atmosphere. There is no question that it is happening, that it is going to cause global warming, and that such changes in the past — even when they are of much lesser magnitude — have had widespread ill effects on human society. What is yet more disturbing is the fact that that conclusion has to be dug painstakingly out of the survey's 22 essays, because the authors themselves, for all their erudition and technical mastery, never proclaim it clearly and unequivocally. Why should that be so? Why is it that, despite some noble exceptions — scholars who have issued unambiguous warnings, though mainly to deaf ears — specialists in the field have failed to make the rest of us acutely aware of the looming hazards? Why do those who really understand what is happening allow themselves to be dismissed so easily as moralistic environmentalists, worried (in the words of a recent New York Times editorial) about "the intangible benefits from preserving the wilderness" and little else?

The essential problem is the congenital hesitancy of the scientific community. Unless every contingency and possibility is absolutely under control, it regards conclusions, predictions, and warnings that go beyond overwhelming evidence as "premature" or worse. From the very first days of its modern origins, science has resolutely set its face against involvement in any matter that cannot be dealt with in total objectivity and certainty. That heritage determines its public posture, status in its ranks, and its neutrality even in the face of major calls on its expertise. There are remarkable exceptions to these sweeping generalizations, of course, but the few practitioners who do behave differently are often regarded with unease by their colleagues, who damn their pronouncements as "unscientific". Like any adult trapped by Freudian forces, scientists are straitjacketed by the circumstances of their discipline's birth.

At the time of the Scientific Revolution that created modern science, the West was wracked by vicious religious and ideological conflicts. Bitter intolerance, ghastly massacres, and vicious wars threatened to tear apart the very fabric of European civilization. The first scientists therefore made it a cardinal rule of their trade that no political, religious, or other controversial subjects were to be discussed at their meetings. Science was to be an oasis in the wilderness of hate and emotion — the very language it was written in was to be simple, unadorned, and objective. And the scientists were enormously proud that their great achievements, not to mention the communications on which they depended, crossed every imaginable hostile line. Mathematics could be discussed in a monk's cell or a Russian court; Protestant could admire Catholic; aristocrat could mingle with plebeian. Those divisions have largely vanished, but the scientists continue to behave as though charged advocacy were a mortal sin. The few who become involved in larger causes risk scorn and consignment to the fringes of their calling.

It is true that science has been drawn into the service of sinister masters. Astronomers have been called agents of atheism; geologists have seemed to justify racial superiority; geneticists have preyed both on colleagues and on the mentally weak; and biologists have condoned genocide. But that has not been the reason for the distrust of passion. Even the many groups of "concerned scientists" that have proliferated in recent years -- ready to pronounce even in areas outside their research competence -- have not dented the careful distancing that the orthodox majority instinctively adopts. And if neutrality is the watchword on limited issues, then portentous doomsday predictions are almost by definition unacceptable behavior.

Unfortunately, a form of doomsday is exactly what climate might have in store for us. Second only to nuclear disaster, changes in the environment are the most potent threat to the continued existence of society as we know it. Yet if the scientific community has a dismal record of rousing public understanding of the full, terrifying implications of nuclear arsenals -- survivability is a word bandied about as it it were a tourniquet for a minor wound -- then on climate it has virtually no record at all. Despite studies by the bushel, and occasional -- albeit usually highly technical -- general discussions of what the future holds, there has been no visible effort to issue the clarion calls that might focus wide attention on the looming forces of climatic change. Average citizens may have some conception of nuclear war, but most would probably define the build-up of carbon dioxide, if given multiple choice, as some type of tooth decay.

This is where objectivity and the committment to research for its own sake have brought us. The studies multiply. The fascinating problems are uncovered and dissected. Techniques of dazzling ingenuity are invented so as to derive -- to give just one example -- temperature records of more than a thousand years ago from the calcium deposits of water seepage in limestone caves. And yet there is no effort to ring tocsins about the unmistakable results of the research. I have elaborated on this problem in a recent contribution to Nature, a copy of which is appended below, but I might here give the gist of that commentary — pointing out what the unmistakable findings are, what is being done (or, more relevant, not being done) about them, and suggesting where we might go from here.

The one inescapable result of all the work, regardless of specialty, is the discovery that trace gases are building up in the atmosphere at a geometric rate, and that an unprecedented warming of the atmosphere may already be well under way. Has that resulted in calls for public education, massive campaigns for remedial action, and fevered portrayals of the dislocations or perhaps catastrophes that may ensue? Not at all. The few who have lit some beacons — Stephen Schneider's Genesis Strategy, with its predictions of ice caps melting and coastal cities inundated, is a rare example — are dismissed as insufficiently "scientific" and untrustworthy at best. Much preferred is a tame call for further study. If nobody can be 100% sure, then obviously the best tack — certainly for the scientists who will get the grants to do the research, as with "Star Wars" — is to keep at it until we can be 100% sure. Too bad if by then it's too late. At least the great scientific tradition of neutrality and restraint will have been preserved. Just one quotation will give the flavor of this outlook:

> An increase in the average temperature by 3 or 4°C could lead to the beginning of an irreversible melting of glaciers. What will the properties of the new state of equilibrium of the biosphere be like; will they permit the existence of man? We do not know.

Know 100%? Perhaps not, but we have a pretty good idea. America's corn belt will no longer grow corn. It may grow in Saskatchewan, but there isn't much soil up there. Trees at home in the temperate zone will not flourish in their current habitat, but will someone have planted them all further north, in their new home? And will we be ready to move them again a few years later? That prospect, moreover, is not a comfortable two centuries away, as we once thought, but maybe just fifty years, and closing fast. Of course we do not know exactly what will happen, and when. But is that a reason for delay, especially since we already know a great deal -- more than enough -- and none of it is pleasant?

The calm about all of this is shattering. And the evasions are extraordinary. In a world of fond hopes, perhaps the trend will not turn out as badly as the indicators now suggest, or the model will prove to have been too pessimistic. Maybe the effects will be cushioned by adaptations similar to those mankind has already shown itself capable of (hopefully without the enormous suffering those experiences brought in their wake). Could it be that we will all somehow muddle through, that it is really somebody else's problem -- the politicians'? -- or that opposing trends will cancel each other out? The latter, couched in such scientificese as "negative feedbacks" which "counteract any wide departure" or even "major excursions" from the norm, presumably require nature somehow to restore the equilibrium. How this might happen is not apparent, though there are those who believe that in fact we are on the brink of a major cooling, as the result of a cyclical return of the ice age, and maybe this would balance out the greenhouse effect.

The scientists' caution about predicting profound dislocations, their trust in the saving discontinuity, is as damaging as the obtuseness of those who cite such a discontinuity for different reasons: the group which, in order to deny that carbon dating is accurate, posits a complete break in terrestrial climate a few thousand years ago, for which the evidence is the absence of rainbows before Noah's Flood. For those who know better, although neutrality may be the path of least resistance, it is one fraught with enormous costs. Scientific tradition, when applied to a subject as charged as this one, becomes an obstacle to understanding and action. The peril of general ignorance is beginning to outweigh the perils of alarmism.

It is true that we also cannot predict exactly what the Carbon Dioxide buildup will change. But history and our own times are littered with societies devastated, destroyed, or merely damaged by climatic forces. From Sri Lanka around 1400 (when a stable society's agriculture was shattered by dwindling rainfall, it succumbed to previously weaker invaders, and cultural divisions were created that plague the island to this day) to Greenland around 1700 (when a flourishing European colony was decimated by declining temperatures), we can see entire populations either wiped out or forced by immense disruptions to move huge distances, totally reconstitute their economies and polities, and dismantle ways of life centuries old. There are dozens such examples, and they do not diminish in our own times, as mere mention of the words "Dust Bowl" or "Sahel" remind us.

In my own field of specialization, early modern European history, the so-called Little Ice Age accelerated the wrenching shift of power away from the Mediterranean, the center of western civilization for two thousand years, to the new powers of the North; it interrupted an enormous population and economic boom that might have stimulated the Industrial Revolution decades before it arrived; and it caused hardship at the local level from Iberia to Russia. This is when the pauperization of southern Italy and Spain began, when the so-called "subsistence crises" promoted starvation and plague at regular intervals throughout the continent, and when governments assumed unprecedented new powers, often termed "absolutist", so as to stave off economic and social disasters. We look back at these eruptions. We see fumbling and usually futile efforts to come to terms with the upheavals, which in every case were totally unexpected. We see debilitating consequences that lasted generations. And yet none of these examples involves a climatic break from the past whose magnitude in the short term even approaches what most studies now tell us — not without warning, but with abundant warning — is likely to happen in the twenty-first century. Can we learn nothing from the past?

The ideal scenario would be for all the scientists who now have unmistakable evidence of accelerating Carbon Dioxide build-up and its future course to join together with the scientists who can determine how each 1° C of annual warming will affect the oceans, the land, the air, and the beautifully rhyming biosphere and cryosphere,, and then unanimously tell the world, in the most dramatic tones possible, of the catastrophic dislocations humanity faces. But that is not what scientists do. Indeed, any attempt to organize such an effort would be viewed with suspicion. One alternative would be for an unimpeachable figure, revered as a leader beyond the range of the snipers, to make the move on behalf of his colleagues. The only time that ever happened was when Einstein wrote his famous letter of 1939 to Roosevelt about German nuclear research. Significantly, though, his later warnings about the dangers of the atom bomb went unheeded.

Yet the reason the Einstein letter worked was the identity of its recipient, and that is why this hearing can still be a beginning, regardless of the mores of the scientific community. What is needed above all is political leadership. In a situation lacking the obvious signs of disaster -- nuclear reactors blowing up, tropical heat waves in February -- but haunted instead by a distant and unseen menace, how else is the world to be galvanized? After all, it is no longer a scientific problem we are facing. The facts are basically in; we know in general terms what lies in store. The baton must pass to those who can make the issues salient and can convince society to face up to their demands -- in other words, to our political leaders.

The tools they need are certainly at hand. Historians, sociologists, and anthropologists have studied dozens of peoples whose lives have been shattered by natural disasters both sudden and slow moving. They have analyzed strategies that have saved communities, and reactions that have merely made bad times worse. It is not too difficult, for instance, to learn why the potato fungus that caused starvation in Ireland in the 1840's had a far less malignant effect, in those same years, on the Dutch, who ate just as many potatoes as the Irish. And we have one enormous advantage even over the environmentally astute Dutch. We have foreknowledge. We can therefore consider now, while there is still time, how we will address the issues that confront us. What *will* we want to do when Washington gets Miami's climate? Are such plans possible? Or do we want instead to seek out preventatives? Is massive, world-wide reforestation feasible? The only way we can answer questions like these is if, first, we admit they are of vital importance, and then, second, we get down to the task of finding out *how* to answer them. We may not know precisely where the quest will end, but it is urgent that we at least repeat the words first spoken not many yards from here; let us begin.

NATURE VOL. 320 17 APRIL 1986 — SPRING BOOKS — 643

What's wrong with being neutral?

Theodore K. Rabb

Climate Impact Assessment. SCOPE Report 27. Edited by Robert W. Kates, Jesse H. Ausubel and Mimi Berberian. *Wiley:1985. Pp.625. £59, $100.*

SCIENTISTS are understandably shy of making doomsday predictions. Even when their investigations uncover what some might consider frightening possibilities, they incline to caution. The calculations are uncertain, extrapolations are full of pitfalls and nobody is sure what the consequences for humanity of specific events might be. No area of science is more fraught with such hesitations than the study of the effects of climatic change.

The editors of *Climate Impact Assessment* have put together a breathtaking survey of what has been accomplished in over three decades of research in four main areas: overall models and frameworks for assessing climatic impacts; the impact in specific sectors such as agriculture and water resources; the impact on particular societies and their response; and the construction (often by modelling) of integrated assessments. But the emphasis throughout is on neutral interpretation. For example, because short-term changes are much larger and therefore mask long-term changes, it is said on p. 42 that one should withhold judgement on the rise in the concentration of carbon dioxide in the atmosphere — this, when 1.5 × 10^{10} tons are being added each year, and an almost equivalent tonnage of ozone is being lost (p.505). Similarly, neither observed changes nor their variability are "significant" (p. 40) — to whom? And narrative descriptions of climatic disasters, containing such rhetoric as "crippling", are to be avoided, because "the unwary reader" may not discern the absence "of a precise framework for gauging the importance of climatic impact" (p. 543). The measured tone, the rap on the knuckles for the few unruly children who do make urgent noises — this is the seventeenth-century heritage of science as an escape from emotion taken (at least for this field) too far.

References to the level of carbon dioxide in the atmosphere recur throughout the 22 essays in this book. But all of the authors treat it as a valuable statistic, as a stimulus to research or as a fascinating academic question. Thus (p. 509):

> An increase in the average temperature by 3 or 4°C could lead to the beginning of an irreversible melting of glaciers. What will the properties of the new state of equilibrium of the biosphere be like; will they permit the existence of man? We do not know.

Those who have suggested they do know, and have foreseen terrifying dislocations as the Earth's landmass shrinks dramatically, tend to be relegated to the fringes of scholarship. They are scarcely mentioned in this book, as if they might somehow tarnish the respectability of the field. One has the feeling that perhaps everyone is hoping that the dire predictions will balance out — that the greenhouse effect might be counteracted by the cyclical return of an ice age — so that what Thomas Kuhn called "normal" science can proceed undisturbed.

Yet the basic facts are inescapable. Given the comment in the quotation above about a 3 or 4° C temperature rise, what is one to make of the 2° C rise that has taken place in Indiana over the past century (p. 61)? One answer emerges unmistakably: recognition of a potential problem is crucial if a society is to have any interest in addressing it. A 30 per cent increase in summer rainfall recently went unnoticed by the citizens of St Louis (pp. 324–326). People do make small adjustments, of course; but what is likely to follow if — as has happened — a fundamental but imperceptible shift takes place, such as a displacement of the northern limit of a particular crop's viability more than 300 km southward over the course of a century (p. 365)? Do we throw more chemicals at it? Relocate or retrain the populations of entire regions?

None of this is to suggest that there is no real concern about the issues in the scientific community. The Carbon Dioxide Information Center at Oak Ridge National Laboratory is one of a number of organizations that keeps trying to draw our attention to the need for both research and action. But it is the former that takes precedence over the latter, and by a long way. A briefer version of the thorough review of the scholarly literature in *Climate Impact Assessment* appeared in Kellogg and Schware's study of the consequences of the build-up of carbon dioxide (*Climate Change and Society*, published by the National Center for Atmcspheric Research in Boulder in 1981). They reached more dramatic conclusions, and linked their call for more research with suggestions of strategies for dealing with the problem. But the practical results have been nil — a response that recalls the Sherlockian dog that failed to bark.

Lucid, precise and abundantly informative though these essays are — I noticed only one misprint that might mislead: 200 on p. 107 should be 2,000 — they do not take the process of public education beyond Kellogg and Schware's book. Perhaps that requires a different kind of effort which, though doubtless likely to attract frowns, is in fact no less admirable than the meticulous overview of research issues and conclusions that these authors provide. There may be uncertainties aplenty, but the expectation of a major warming during the twenty-first century now seems to be almost universally shared. In addition to refining the tools by which this process should be measured and assessed, scholars now have the responsibility to specify more urgently the dislocations that are likely to ensue. This book is a foundation for that step: it identifies the topics and findings on which all future work must build. But one has to regret that the learned and superbly qualified authors who produced it have held back from attempting to offer the sharp and unambiguous conclusions that could have served to educate a wider public. ☐

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Within Saturn's rings — detail of a painting by William K. Hartmann (the original is in colour). The illustration is reproduced from Out of the Cradle: Exploring the Frontiers Beyond Earth, *by Hartmann, Ron Miller and Pamela Lee, published by Workman, New York. Price is hbk $19.95; pbk $11.95.*

CMA
CHEMICAL MANUFACTURERS ASSOCIATION

STATEMENT OF
S. ROBERT ORFEO
ALLIED-SIGNAL INC.

ON BEHALF OF THE
CHEMICAL MANUFACTURERS ASSOCIATION
BEFORE THE
SUBCOMMITTEE ON ENVIRONMENTAL POLLUTION
OF THE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

REGARDING
POTENTIAL CHANGES IN ATMOSPHERIC
OZONE LEVELS AND THE GREENHOUSE EFFECT

JUNE 11, 1986

2501 M Street, NW • Washington, DC 20037 • Telephone 202/887-1100 • Telex 89617 (CMA WSH)

The Fluorocarbon Program Panel (Panel) of the Chemical Manufacturers Association (CMA) welcomes the opportunity to address the Subcommittee on Environmental Pollution on the issues of potential changes in atmospheric ozone levels and the greenhouse effect. The Panel represents most of the world's chlorofluorocarbon (CFC) producers. CFCs serve critical needs in refrigeration, air conditioning, and other diverse uses that are considered highly beneficial by society.

The Fluorocarbon Program Panel shares the concern of the Subcommittee on atmospheric ozone levels and the greenhouse effect. The Panel believes that these global issues require international cooperation on research and monitoring. Based on this belief, the Panel began a research program 14 years ago to understand the potential effects of CFCs on the global environment. This program is coordinated with and complements research of government agencies in the United States and in other countries. The most recent review of atmospheric research programs[1] shows that much progress has been made, but much remains to be learned. Based on research to date, in the judgement of the

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[1] Atmospheric Ozone 1985: Assessment of Our Understanding of the Processes Controlling its Present Distribution and Change," WMO, Global Ozone Research and Monitoring Report #16.

Panel, continued releases of CFCs will not pose a significant threat to the environment during the time required to gain a better understanding of the science. Continuation and augmentation of existing research programs will improve our understanding of the global environment and will provide a scientific basis for future courses of action.

The Fluorocarbon Program Panel is an international group representing 19 CFC-producing companies from 10 countries. Its research program, administered by CMA, was initiated in 1972, to investigate the potential effects of CFCs on the environment. Over the years, the program has expanded its activities greatly. While its work remains focused primarily on the issue of potential changes in atmospheric ozone levels, it also includes work on the greenhouse effect. It has spent in excess of $18 million to date on research, and has had an annual budget of about $1.8 million in recent years. At least an equivalent amount has been spent by individual companies in support of this program.[2] These figures do not include work conducted by individual companies on substitutes for CFCs. The Panel itself does not conduct any cooperative work in this area.

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[2] The research figures do not include administrative costs, nor the costs of complementary in-house research efforts incurred by individual supporting companies.

The Panel's research program is aimed at improving the understanding of atmospheric processes and fostering long-term monitoring activities. The Panel is unique among groups supporting research on the ozone and climate issues in having the freedom to fund projects anywhere in the world. The Panel solicits proposals and funds research in government, university and private laboratories around the world. This has enabled the Panel to play a key role in promoting international cooperation in many research programs. The Panel's research program is balanced among atmospheric and laboratory measurements, atmospheric modeling, and statistical data analyses and interpretation. Further details of the Panel's recent research activities and future plans are given in the Attachment, prepared for our participation at the February 1986 meeting of the United Nations Environment Programme (UNEP) Coordinating Committee on the Ozone Layer.[3]

In addition, the Panel's research program addresses specific scientific questions. The most recent example is the work currently under way to understand the recently observed decrease in ozone in the Antarctic spring. A number of hypotheses have been proposed to explain this phenomenon; only some involve CFCs. Scientists agree that more data are needed to understand the observations, to test the hypotheses, and to establish a credible explanation. The Panel is cooperating with government agencies [in the United States: the National Aeronautical and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF)] in planning and funding campaigns of atmospheric measurements over Antarctica in 1986 and 1987. Simultaneously, the Panel is supporting laboratory studies, modeling projects, and data analysis programs to better understand the phenomenon.

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[3] A summary of the Panel's entire research program can be obtained from the CMA Fluorocarbon Program Panel.

An example of the Panel's role in fostering long-term measurements is the Atmospheric Lifetime Experiment (ALE), now the Global Atmospheric Gases Experiment (GAGE). The Panel initiated this successful world-wide automated network to measure atmospheric concentrations of CFCs in order to establish their lifetimes. Funding of this international network has largely been taken over by government agencies (for the United States: NOAA and NASA). The concentrations of other greenhouse and potential ozone modifying gases, including methane and nitrous oxide, are also measured at the GAGE sites.

The Panel has also funded the application of sophisticated statistical methods for analyzing long-term records of ozone data for possible trends. Again, this is a cooperative effort with researchers from government agencies and universities. The results of such trend analyses show that there has been no significant change in globally averaged total ozone. This finding is in agreement with model calculations. It is the total ozone level that controls the amount of ultraviolet radiation reaching the earth's surface. A recent analysis of a more limited and less reliable data set indicates that upper stratospheric ozone has decreased. This result is also in qualitative agreement with model calculations, but its significance is not yet understood.

While it is recognized that analysis of ozone data can identify an effect, it cannot establish cause. Furthermore, model calculations suggest that there are much more sensitive indicators of potential stratospheric change than measurement of ozone itself. A critically needed program to monitor these indicators is being explored by NASA, NOAA, and the Panel, and should be supported. This program is an early detection network of ground-based monitoring stations. The main purposes of this network would be to: identify any changes in key atmospheric species; provide information on the causes of such changes; and most importantly, warn of future significant changes in ozone that may be induced by human activities well before they would actually occur. The feasibility of such a network was established at an international workshop held in Boulder, Colorado in March 1986.

The workshop was sponsored jointly by NASA, NOAA and the Panel.

Initiating the early detection network, described at the Boulder workshop, would require a three part effort: adding a number of instruments at existing monitoring locations; establishing new sites; and continuing the current satellite and ground-based monitoring systems. Data from this network would provide additional constraints to test the models. It would also act as a calibration system for satellite-borne monitoring instruments, thereby resolving concerns about their intercomparability and calibration drift. The early detection system, coupled with the evidence that there has been no change in total ozone and the fact that model calculations show no change in total ozone for the next two to three decades, gives us confidence that time is available to conduct the research and monitoring necessary to establish the credibility of the long-range predictive capabilities of models. Based on the science, in the judgment of the Panel, there is no justification for additional regulations at this time.

The other issue the Subcommittee has under consideration today, is the greenhouse effect. CFCs are minor contributors to the greenhouse effect, the major contributor being carbon dioxide. To better understand the relationship of CFCs to the greenhouse effect, the Panel funds a two-dimensional (altitude and latitude) modeling effort. Two-dimensional models bridge the gap between simple one-dimensional (altitude only) models and much more realistic but very costly three-dimensional models. The magnitude of the total greenhouse effect is very uncertain due to our lack of understanding of factors such as clouds that can either decrease or increase the direct contribution of the many "greenhouse gases." The relative contribution of CFCs, however, can be calculated with reasonable certainty. At the present time, CFCs are calculated to contribute about 15% of the total effect. Future contributions of all trace gases will depend on their relative growth rates.

The existing U.S. Government programs have been instrumental in developing the current understanding of atmospheric sciences. These programs have advanced the understanding of processes controlling atmospheric ozone and climate. However, much more work is needed to quantify these processes and to determine the nature and the extent of the potential effects of man's activities on ozone and climate. Existing and planned programs should provide steady progress toward the goal of quantifying the theories of ozone and climate modification. These programs must continue to receive adequate funding if this goal is to be reached.

As scientific understanding has matured, the importance of long-term monitoring through an early detection network has been identified. Such a ground-based network, described earlier in this testimony, would serve several purposes. It would provide an early warning of significant changes in stratospheric ozone, provide additional data needed to improve model simulations of the atmosphere, and provide a reference set of measurements for comparison with satellite data. Establishing and maintaining the early detection network requires a long-term international funding commitment. The U.S. must continue to play a lead role in atmospheric sciences by not only maintaining existing and planned research and monitoring programs but also by fostering the implementation of this early-detection network. This can be done by rapid deployment of network stations at U.S. sites, cooperating with scientists and agencies from other countries on development and deployment of stations on foreign sites, and providing adequate travel funds for government scientists to participate in this international program. This last issue of travel funds is a critical point that is essential to the success of the program.

Addressing long-range global scientific issues requires long-term international cooperation and commitment, which should be promoted through international bodies, such as the World Meteorological Organization and UNEP. The Panel, for its part, plans to continue its long-standing role in funding international research activities.

FACT SHEET

FLUOROCARBON PROGRAM PANEL (FPP)

- Chlorofluorocarbons serve critical needs in refrigeration, air conditioning and other diverse uses that are considered highly beneficial by society.
- The FPP has committed in excess of $18 million for scientific research on ozone and climate issues. This international science program is coordinated with and compliments those of government agencies.
- The FPP, along with researchers from government agencies and universities, conducts analyses for trends in the long-term records of ozone data. The results show no significant change in globally averaged total ozone.
- Model calculations predict no change in total ozone for the next 2 to 3 decades.
- Based on scientific evidence, in the judgment of the Panel, continued releases of chlorofluorocarbons will not pose a significant threat to the environment during the time required to gain a better understanding of the issues.
- Several suggestions have been offered to explain the observed decrease in ozone over Antarctica but none have been confirmed; scientists agree more data are needed to establish a credible explanation. The FPP is cooperating with government agencies and sponsoring private research in this area.
- The FPP call on the U.S. government to maintain support of current research and monitoring programs, augmented by an early detection network with a long-term funding commitment.
- Two-dimensional (altitude and latitude) climate modeling shows that chlorofluorocarbons are minor contributors (about 15%) to the greenhouse effect; the primary contributor is carbon dioxide.

Attachment

CHEMICAL MANUFACTURERS ASSOCIATION
FLUOROCARBON PROGRAM PANEL

Recent Research Results and Future Directions

February 1986

INTRODUCTION

In 1972, chlorofluorocarbon (CFC) manufacturers began supporting research to investigate the effects of CFCs on the environment. This program has been expanded greatly to help determine the extent to which these compounds may affect the stratospheric ozone layer. The Fluorocarbon Program Panel (FPP), administered by the Chemical Manufacturers Association (CMA), is supported by 19 CFC manufacturers from North America, Europe, Japan, and Australia.

FPP has reviewed to date about 580 research proposals, and projects totalling about $18 million have been funded worldwide. Calendar 1986 commitments are expected to total about $1.8 million. This summary describes some of the recent and ongoing work supported by FPP. A more detailed research summary can be obtained from the CMA.*

SCOPE OF PROGRAM

FPP sponsored research has made a major effort toward estimating and interpreting changes in total column ozone, the ozone profile, and the temperature profile over the last decade and a half. This research has been an interdisciplinary effort involving statisticians, meteorologists, and modelers. Sensitivity analyses of trends to data quality concerns (e.g., instrument calibrations), natural events (e.g., solar variability, volcanic aerosol), statistical model formulation, and bias correction factors have been done in part and will be a focus of future work. Discrepancies and similarities between trend estimates and chemical model calculations have been flagged for further study.

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FPP continues to sponsor three one-dimensional (1-D) modeling programs as well as a two-dimensional (2-D) model development program. Capabilities of 1-D models include fully coupled radiative-convective/chemistry models, diurnal models, and models capable of time-dependent/multiple perturbation scenario calculations as well as the standard diurnally averaged 1-D chemical models. A 2-D model has the additional capability of simulating the latitudinal and seasonal distribution of stratospheric trace gases. The goal of the 2-D model development program is to develop a fully coupled stratospheric 2-D model with interactive dynamics, radiation and chemistry.

The FPP supported chemistry program is designed to improve understanding of the kinetic and photochemical data base needed to calculate possible changes to stratospheric ozone. To these ends, FPP supports studies of reactions already included in models as well as exploratory studies of reactions that could affect calculated ozone alterations but are not currently included in models.

The atmospheric measurements program of FPP sponsors research to obtain observational data that test and extend knowledge of atmospheric processes related to the stratospheric ozone layer. These data play a crucial role in testing atmospheric models and hence in understanding the present day atmosphere and assessing the reliabilty of predictions of its future composition.

FPP also reports production data for CFCs 11 and 12, sponsors climate modeling, and follows research on biological effects that may result from altered ozone levels.

1. OZONE TREND ANALYSIS

The FPP continues to fund statistical analyses of atmospheric ozone measurements for evidence of ozone changes. Based on the total column ozone measurements recorded at 36 Dobson stations since as early as 1958, trend determinations of globally-averaged ozone for the period 1970-1982 yield values that are not distinguishable from a zero trend in terms of statistical significance. However, the analyses for long term trends have been complicated by effects possibly due to volcanic aerosols from the El Chichon eruption in March-April of 1982, an anomalously warm sea-surface temperature effect in the equatorial Pacific (El Nino phenomenon) in 1982-1983, and the effect of the quasi-biennial oscillation (QBO). Estimated trends in total column and profile ozone may well be distorted by lower ozone values following these events.

The focus of the FPP sponsored program is to carry out competent, credible, and critical analyses: 1) to quantify any changes or trends in total column ozone, the ozone profile, and the temperature profile; 2) to compare results with chemical model calculations; 3) to estimate the early warning capability and thresholds of trend detection (i.e., the 95% confidence limits); 4) to evaluate problems in data quality and assess approaches to account for measurement biases and natural perturbations; 5) to bring together scientists responsible for obtaining data and for its statistical analysis; and, 6) to develop and extend the methodology needed for spatial and time dependent trend analyses.

Analyses have been made on total column ozone data from: 36 Dobson stations through 1984; balloon ozonesonde profile data through 1983 from 13 geographical sites (12 in the N. Hemisphere and 1 in the S. Hemisphere); and Umkehr ozone profile data through 1984 at 11 N. Hemisphere stations (through 1981 at 13 stations of which one was in the S. Hemisphere). In these studies the Dobson total ozone records range from 15 to 27 years in length. The records for stations in the Umkehr network range in length from 10 to 24 years and in the ozonesonde network from 7 to 17 years.

Total Column Ozone: Nimbus 4 satellite data for 1970-1977 show that the current 36 station Dobson network used in these analyses has adequate global representation for trend analysis. The average satellite trend result over the 36 locations is similar to the globally averaged satellite trend estimate.

Low total ozone values of about 5% below normal in the winter of 1982-1983 appear to have affected the trend estimates. For example, trend estimates by a team of researchers at the Universities of Chicago and Wisconsin were +0.02 ± 0.94%/decade (95% confidence limits) for the period 1970-1982, -0.17 ± 1.10%/decade for 1970-1983, and -0.26 ± 0.92%/decade for 1970-1984. Although none of these estimates was statistically different from a zero trend, natural events in 1982-1983 such as the El Chichon volcanic eruption, equatorial sea-surface warming, and QBO appear to have had some effect.

The trend modeling approach by Princeton University statisticians appears to be even more sensitive to these events. For example, their total ozone trend estimates were -0.67 ± 1.02%/decade for the period 1970-1982, -1.10 ± 0.94%/decade for 1970-1983, and -0.70 ± 0.82%/decade for 1970-1984.

Including data through 1984, neither group finds evidence of a statistically significant change in total column ozone. This is consistent with chemical model calculations that take into account all trace gases.

Sensitivity studies now in progress examine the differences in approach between the two research groups. These differences include the time period covered prior to 1970, regional weighting factors, methods of adjustment for solar and seasonal variations, and analysis method. These studies indicate that the generally more negative trend values from the Princeton group can be explained in large part by the shorter length data set used. The Wisconsin/Chicago team include data taken as early as 1958 at some stations, whereas the Princeton work has used only data after 1963. When the Princeton analysis is modified to include 1960-63 data, the trend estimates become less negative by about 0.5%/decade.

It will be important to continue trend analyses, given that the anomalously low ozone values may represent a transient excursion due to natural effects which temporarily obscures any longer term trend in the ozone layer. Work is underway to reexamine recent data and continue to improve the methodology for its statistical analysis. Future work includes expanding the data base to include Russian stations and more Dobson stations and evaluating six years of Nimbus 7 satellite SBUV data (1978-1984).

Profile Ozone: FPP supports studies on statistical analysis of ozone profile data from the Umkehr network, balloon ozonesondes, and the Nimbus 7 satellite. Since the original Nimbus 7 data set includes only four years of data -- barely adequate for trend analyses -- and has recently been reprocessed with another two years of data, only the Umkehr and ozonesonde studies have been analyzed beyond the preliminary stage so far.

A joint research team of statisticians and atmospheric scientists from the Universities of Wisconsin and Chicago, the U.S. National Aeronautics and Space Administration (NASA), the U.S. National Oceanic and Atmospheric Administration (NOAA), and the Canadian Atmospheric Environment Service has analyzed the Umkehr and balloon ozonesonde profile data. Umkehr measurements range from the lower troposphere (0-5km) to the upper stratosphere (43-48km), with the best trend precision between 25 and 40km. The ozonesonde data are collected from the lower troposphere up to a height of approximately 30-35km, with the best precision in the 15-28km region.

Statistical trend analyses have been made using the Umkehr data between Umkehr layer 5 (24-29km) and Umkehr layer 9 (43-48km). Layer 8 (38-43km) has been of particular interest since it is the region of the stratosphere calculated by chemical models to show the largest percentage effect from chlorinated compounds such as CFCs. The trend analysis models have used terms to adjust for instrumental recalibrations, solar variation, and volcanic aerosol interferences. Written correspondence with the ozone recording stations confirmed that all known updates and corrections were included in the data analyzed.

Volcanic aerosols interfere with the Umkehr measurements, leading to apparent lower ozone values in the upper Umkehr layers. The volcanic aerosol loading has been approximated by using the Mauna Loa solar transmission data with different terms in the statistical models for before and after the El Chichon volcanic eruption. Both the Mt. Agung eruption in 1963 and the El Chichon eruption in 1982 added significant aerosol loadings to the atmosphere as reflected in the Mauna Loa solar transmission data. In order to be meaningful, trend analysis must accurately adjust for this type of event. An apparent ozone increase in the 1960's, as derived from Umkehr measurements, correlates with a diminishing aerosol effect, as seen in the Mauna Loa transmission data following the M. Agung eruption. Thus, whether the Mauna Loa transmission data are globally representative is important to the accuracy of the correction procedure. There is evidence that they are not. Peak aerosol loadings measured by Lidar and satellite at other locations were much higher than those measured at Mauna Loa after the Mt. St. Helens and El Chichon events. Aerosol particle size and altitude profile distribution may also cause biases in the correction procedure that are not yet accounted for in the analyses. Intensive work is in progress to include post El Chichon Umkehr data in ozone trend analyses.

With these caveats, for the aerosol-corrected data from 12 N. Hemisphere Umkehr stations and 1 S. Hemisphere station studied by the above team of scientists, trend estimates of the average ozone change for the period 1970-1981 (prior to the El Chichon eruption) are:

Layer 9 (43-48km)	-0.32 ± 0.33 %/year
Layer 8 (38-43km)	-0.32 ± 0.17 %/year
Layer 7 (34-38km)	-0.26 ± 0.17 %/year
Layer 6 (29-34km)	+0.04 ± 0.16 %/year
Layer 5 (24-29km)	-0.03 ± 0.16 %/year

The error bars are the 95% confidence limits from the statistical analysis, revealing that the trend estimates in layers 7 and 8 are statistically significant. Aerosol and solar adjustments were done using the Mauna Loa transmission series and the f10.7cm solar flux data respectively.

The addition of 1982-84 data, which are highly affected by volcanic aerosol interference, makes the preliminary trend estimates in layers 8 and 9 slightly more negative. The adjustment for the volcanic aerosol after the El Chichon eruption is complicated by the amount and location of the aerosol burden and there is a reluctance by the researchers to report quantitative trend results until these effects are more thoroughly studied.

Future FPP sponsored studies will focus on how well the Mauna Loa transmission data represent the aerosol loading for each of the Umkehr stations. The FPP has sponsored a study to acquire astronomical extinction data collected since 1960 at 14 locations which may be used to evaluate aerosol global distribution for Umkehr data correction. In addition, efforts will be made to determine how other Umkehr layers affect the 40km trend estimate since the amounts of ozone in the different layers obtained from the Umkehr retrieval algorithm are highly correlated, and hence the layer trend estimates do not provide truly independent pieces of information. Also, trend estimates will be further compared with model calculations to determine critical areas of agreement or disagreement with respect to solar, temporal, and geographical factors. Calculations with 2-D models for the coupled scenarios (e.g., CFCs, CO_2, N_2O, NO_x, and CH_4) will be of crucial importance here.

A recently installed automated Dobson network of seven stations, the installation co-funded by FPP, will enhance the Umkehr analyses in the years to come by providing more frequent, higher quality Umkehr observations and better global coverage. Continued government funding support is, therefore, essential.

The joint research team has analyzed balloon ozonesonde data from 13 locations. A total of 15 layers or height regions ranging up to 33km were considered. The team is addressing a number of possible sources of error in the measurements which may introduce errors in the analyses. Work to date using different correction procedures gives estimates suggesting an increase in ozone in the 0-5km region and a decrease at 15-21km. However, this does not agree with 1-D model multiple perturbation calculations which indicate a negligible change at 15-21km and a much smaller increase than observed at 0-5km. Inclusion of data from 1983 made the estimates for 15-21km more negative, indicating a possible effect due to natural events such as the El

Chichon eruption. Further analyses and comparison with 2-D model multiple perturbation calculations are needed.

Future efforts include comparisons of Umkehr and ozonesonde profiles below 30km on a regional and station-by-station basis to check for consistency in the lower stratosphere trends. Seasonal variation in trends will also be evaluated. The six years (1978-1984) of Nimbus 7 ozone profile data will be used to determine the global representativeness of the ozonesonde network.

Temperature: Princeton University scientists have analyzed 1964-1979 atmospheric temperature data (radiosondes) at nine altitude levels ranging from 1 to 24km. Data from a total of 154 stations were used and the data were divided into nine latitudinal zones. Trend estimates for each pressure (or height) level were fitted, with adjustments for station-to-station and within-station variation. The characteristic shape of the estimated trend profile through 1979 was a cooling above 16km and a warming below. Another study is currently being done by the Wisconsin/Chicago research team using data through 1983.

2. MODELING

Time-dependent calculations which account for changes in concentrations of the potential ozone modifying source gases (CFCs, CH_4, N_2O, and CO_2 in multiple scenario calculations) provide the best available estimate of near term changes in the ozone layer. However, the limitations of the calculations due to uncertainties in model formulations, chemical data, and future concentrations of source gases must be realized. The program results have identified two requirements:

- periodic updating of the multiple scenario/time-dependent calculations, and

- calculations based on future scenarios should not be extended beyond the next few decades (except for model intercomparison purposes) to avoid introducing overwhelming uncertainties in projected future source gas concentrations.

Multiple scenario/time-dependent calculations have been made using a 1-D model to estimate future changes in the ozone layer. These calculations continue to show that total column ozone is not likely to change significantly during the next few decades for reasonable assumptions of future source gas concentrations. The scenario chosen for this study, and discussed in WMO 1986, was: 1.0%/year increase in CH_4 concentration, 0.25%/year increase in N_2O concentration, 0.5%/year increase in CO_2 concentration, and 1.5%/year increase in the release rate of CFCs for 1980-2000 and constant release thereafter. The resulting changes in total column ozone are given for several years in the table.

Year	O_3%
1985	0.0
1990	-0.13
1995	-0.26
2000	-0.40
2005	-0.54

The FPP second generation 2-D model, based on diabatic circulation formulated on isentropic coordinates, has been further refined. Compared to the first generation 2-D model it provides a more realistic treatment of transport since it involves only observed temperature fields and one small eddy diffusion term. The transport in the model has been tested with long lived trace gases involving simple chemistry, such as the upward diffusing species N_2O and CFC 11, and the downward diffusing species, HF, with satisfactory results. The complete photochemical scheme, including a diurnal code, has been successfully interfaced with the advective transport code. As a result of these model developments and refinements, the calculated seasonal and latitudinal zonal mean distribution of total column ozone are in reasonable agreement with observations. However, there are important differences between model calculated and observed local densities of ozone at certain altitudes, i.e., 40-50km.

The capability to couple feedback effects from chemistry, dynamics, and radiation will be incorporated into the 2-D advective transport model in the coming year. Ongoing activities include: the development of an efficient radiation scheme to calculate the solar and thermal radiation budget; diabatic heating rates from the temperature and ozone fields; and the development of a dynamical model to calculate zonal wind. Longer range plans call for establishing the feasibility of coupling a tropospheric climate model to the stratospheric model; determining the importance of tropospheric/stratospheric interactions; and, if feasible and necessary, development of a coupled 2-D tropospheric/stratospheric model.

Incorporation of the most recently revised rate data and physical constants into 1-D and 2-D models has not resolved many of the discrepancies between observed and calculated values of important trace species. Significant differences still exist between observed and calculated ozone values above 40 km. Since this is a region in which transport does not play an important role and the ozone chemistry is relatively simple, it suggests that resolution of these differences may require the introduction of new chemistry into the model.

The total nitrogen (NO_y) concentration in the lower tropical stratosphere calculated in the 2-D model is considerably lower than the concentration deduced from satellite HNO_3 and NO_2 observations. A trace gas budget study reveals that the abundance of NO_y in the lower tropical stratosphere is maintained by transport of NO_y from the upper troposphere rather than by in situ production processes. If lightning is included as a source of tropospheric NO_y, the calculated concentrations of NO_y in the lower tropical stratosphere are in much better agreement with observations.

Model simulation of the observed diurnal behavior of stratospheric reactive species (e.g., ClO) is important for understanding their short term response to diurnal variations of solar insolation. Model calculations have been carried out to determine the effect of the revised reaction rate and physical constant data on the diurnal variation of ClO. The calculated day to night ratio of ClO is about the same as previous results and in good agreement with observations. Previous conclusions about the roles of $ClONO_2$ and HOCl in modulating the diurnal variation of ClO remain valid. The large diurnal variation of ClO in the mid-stratosphere (30-40km) is mainly due to rapid exchange between ClO_x (Cl + ClO) and $ClONO_2$, whereas the diurnal variation in the upper stratosphere (40-50km) is due to exchange between ClO_x and HOCl. However the new calculated daytime column density of ClO is about 12×10^{13} molecules cm^{-2} and is almost a factor of two higher than the mean of observed values.

Vertical profiles of HCl and $ClONO_2$ have been calculated and compared with recent observations. The calculated $ClONO_2$ agrees well with observations but the calculated HCl concentrations at around 25-35km is about a factor of two lower than observed. A comparison of the calculated values to observations shows that the models may be overestimating the ratio of ClO/HCl (by approximately a factor of four) in the lower stratosphere, a discrepancy suggesting that the partitioning of Cl_y is not correctly calculated by current photochemical models. These and other discrepancies between model calculations and atmospheric measurements show that significant uncertainties remain in understanding the processes controlling stratospheric ozone and other trace gases. Hence there is a need to continue research to improve understanding of the current atmosphere and to improve capabilities to forecast future ozone levels.

The steady state 2-D model calculations including growth only in CFC emissions have been carried out to evaluate the effects of high chlorine scenarios on ozone levels. The initial results show that even at three times current emission levels there is no indication of a non-linear effect. In contrast to 1-D model calculations, the calculated amount of ozone change at each latitude and season is found to be in direct proportion (linear) to the stratospheric chlorine abundance. This underscores the importance of meridional transport and self healing processes, i.e., increases in ozone production in the tropics due to ozone reduction in the stratosphere. It also confirms the continuing value of statistical techniques of ozone trend analysis to provide early detection of ozone change.

Detailed steady state and time dependent calculations with a 1-D model have shown that the magnitude and onset of the calculated non-linear effect is a function of present day total nitrogen concentration in the stratosphere; the rate of growth of not only CFC emissions, but of CH_4, N_2O, and CO_2; and transport effects. Time dependent coupled 1-D calculations incorporating consensus growth scenarios for the other key trace species show that, at double present CFC production rates/emissions, the calculated effect of CFCs on ozone is significantly moderated, i.e., from about -15% for CFCs only to about -6.6% for the more realistic multiple perturbation scenario case.

The 2-D high chlorine scenario calculations have been extended to coupled steady state calculations. The initial results show that the calculated effects of CFCs are significantly moderated by the calculated effects due to increases in the atmospheric concentrations of CH_4 and N_2O. The calculated reductions in column ozone vary strongly with latitude and seasons. The largest ozone change is calculated to occur in winter at high latitudes.

3. ATMOSPHERIC CHEMISTRY

During the last year, FPP-funded studies have helped to show that the homogeneous reactions of $ClONO_2$ with both HCl and H_2O are too slow to be important in stratospheric chemistry. One study gave an upper limit of 2×10^{-21} cm^3 $molecule^{-1}s^{-1}$ for the rate constant for the reaction of $ClONO_2$ with H_2O. Another study supported the conclusion that the rate constant for the reaction between $ClONO_2$ and HCl is slower than 10^{-18} cm^3 $molecule^{-1}s^{-1}$. Both studies were conducted at 298K. If the rate constants for these reactions had been faster, as tentatively reported at the time of the last CCOL meeting, the calculated effect of CFCs on ozone in atmospheric models would have increased.

The UV absorption cross section of NaCl has recently been measured at 300K in an FPP supported study. The results lead to a calculated photolysis rate for NaCl at 40km of $(1.9 \pm 0.8)\times10^{-4}$ s^{-1}, a factor of 10 smaller than previously estimated using high temperature cross section data. This value limits, but does not eliminate, the possibility that sodium chemistry may play a role in partitioning chlorine between Cl/ClO and HCl in the upper stratosphere. More work is needed to determine the role of both heterogeneous and homogeneous processes that could remove sodium compounds from the stratosphere.

If a sufficient fraction of the modeled ClO were to exist as the adduct $ClO.O_2$, the calculated effect of CFCs on stratospheric ozone could be significantly changed. The effective rate constants as well as the products of reactions involving ClO could be different. More importantly, $ClO.O_2$ could photolyze to produce ozone. To determine the potential importance of $ClO.O_2$, the FPP is sponsoring a study of the equilibrium constant for the reaction:

$$ClO + O_2 \rightleftharpoons ClO.O_2$$

One of the most significant sources of uncertainty in chemical modeling is the degree of penetration of solar ultraviolet radiation into the atmosphere, a process which is controlled primarily by absorption by oxygen. FPP funded a recently completed study of the Herzberg continuum absorption cross section of oxygen in the 194-240nm region. The results confirmed the conclusion drawn from in situ solar irradiance measurements that the previously accepted cross sections were about 35% too large. A project to parameterize the detailed laboratory oxygen absorption cross section data for use in atmospheric models is in progress. The goal of this project is to provide an accurate parameterization of the new high quality laboratory data, thus reducing the uncertainty that exists and encouraging the use of a single state-of-the-art parameterization by modelers.

The HO_x family is probably the most important group of compounds in the stratosphere because reactions involving these compounds control the partitioning between the active, or potentially ozone depleting, and inactive compounds of the other groups. The reaction between OH and HO_2NO_2 is responsible for removing about half of the HO_x in model calculations for the lower stratosphere. Yet the uncertainties in the reaction parameters that control the HO_2NO_2 concentrations are very large. The level of uncertainty is increased by the fact that there have been no measurements of atmospheric concentrations of HO_2NO_2. The FPP is supporting studies of two of the more important reactions involving HO_2NO_2 whose rate parameters are still very uncertain, namely the photolysis of HO_2NO_2 and its reaction with OH.

The FPP sponsored a workshop on atmospheric chemistry at Göttingen, FRG, in October 1984. Leading atmospheric scientists from the United States and Europe met to discuss outstanding questions on the chemistry of stratospheric ozone. Copies of the proceedings of this workshop can be obtained from CMA.

4. ATMOSPHERIC MEASUREMENTS

The FPP continues to support research projects aimed at expanding the observational data base and developing or improving instruments to measure stratospheric composition more accurately.

The results of five years of measurements by the Atmospheric Lifetime Experiment (ALE) will be published soon. They provide information on the concentration trends of the source gases (including methane, nitrous oxide, and CFCs) needed as input for model calculations. The atmospheric lifetimes of 75 years for CFC 11 and 110 years for CFC 12 provide a constraint for the models. The ALE program has now been succeeded by the Global Atmospheric Gases Experiment (GAGE) which is co-funded by NASA, NOAA, the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia, and the FPP.

The FPP continues to co-fund balloon campaigns aimed at simultaneous measurements of a wide range of stratospheric compounds and intercomparisons of different techniques for measuring the same compound. The simultaneous measurements provide information to test the model chemistry. The intercomparisons determine what portion of the previously measured atmospheric variability of compounds is due to instrument error as opposed to real variability. Two recent campaigns of this type are the Balloon Intercomparison Campaign (BIC) and the Middle Atmosphere Program (MAP/GLOBUS) NO_x campaign. These intercomparison campaigns have undoubtedly improved the quality of measurement data by revealing unsuspected deficiencies that could be corrected. Results from BIC for certain key molecules (HCl, HF, HNO_3) give confidence in the stratospheric vertical distributions obtained. More work is needed to understand the discrepancies among instruments for other gases such as CH_4 and NO_2.

FPP provides co-funding of projects to measure HO_x compounds and total chlorine by balloon-borne instruments. Recent results of HO_x measurements provide conflicting information about their concentrations and partitioning. Thus it is critical to continue these programs to determine if the conflicting information is a result of instrumental problems or deficiencies in the understanding of stratospheric chemistry. The total chlorine measurements are expected to provide a test for the completeness of model input data.

FPP has co-funded several instruments that measure the abundance, vertical distribution, and diurnal variability of ClO. Although there is now reasonable agreement between theory and observations for the average altitude profile and diurnal behavior, existing data are inadequate to test the calculated seasonal, latitudinal, or long-term trends.

Although direct involvement in satellite based measurement programs is beyond the scope of the FPP activities, funding is provided to assist in the interpretation of the atmospheric composition data that are now becoming available from satellite instruments. These types of projects are particularly important to provide tests for 2-D models. One such project has derived OH fields using several approaches.

FPP is funding work in several laboratories to measure pressure-broadening coefficients and line positions of key trace species as well as spectra of species that may cause interferences in the measurement of minor trace gases. These results will support measurements made by the ATMOS instrument on board the Space Shuttle, the far infrared Fourier Transform emission spectrometers, and other instruments. Infrared band strength data needed to assess the significance of CFCs to the radiative balance of the atmosphere are being obtained.

The FPP atmospheric measurements program has strongly supported ground-based measurements systems by co-funding millimeter-wave, infrared, and Lidar projects. The developmental work resulting from these projects is expected to play a key role in an Early Detection Workshop, co-sponsored by NASA, NOAA, and FPP and scheduled for March 5-7, 1986. The goal of the workshop is to set priorities and determine capabilities for measuring atmospheric parameters in order to determine trends in atmospheric composition well before changes in stratospheric ozone concentrations could become significant. An early detection network could then be designed to augment and strengthen existing "early warning" measurement programs. Future FPP funding for atmospheric measurements will take into account the need for implementation of such a network.

5. OZONE MEASUREMENTS

FPP has co-funded a project to establish automated Dobson ozone monitoring stations in strategic locations around the world. Since the last CCOL report additional stations have been established in Australia and Peru, and a third S. Hemisphere site in New Zealand is under evaluation. Further information is in "1. OZONE TREND ANALYSIS" above.

6. PRODUCTION AND RELEASE OF CFC 11 and CFC 12

FPP has continued to collect and report production, sales, and release data for CFC 11 and CFC 12. The latest report, recently made available to CCOL, covers production, sales, and releases through 1984. Efforts to obtain reliable data from the U.S.S.R., Eastern Europe, and P.R.C. have been unsuccessful but continue. Therefore, the last two reports contain data from reporting companies only.

7. CLIMATIC AND BIOLOGICAL EFFECTS

FPP is concerned with the effect of possible changes in solar UV radiation on terrestrial and aquatic biological systems, including the human race, and on world climate.

FPP sponsored a sophisticated statistical analysis of the available epidemiological data on the incidence of non-melanoma skin cancer (NMSC). The purpose of the project was to provide scientific perspective as to the validity of predictions of the change in incidence of NMSC with various postulated changes in solar UV-B radiation.

FPP is also sponsoring a two-year program, now in its second year, with the objective of developing a 2-D climate model.

In 1985, FPP sponsored a workshop in Arles, France, on the scientific status of climate modeling and possible effects on world climate due to changes the global average temperature. Copies of the proceedings of this workshop can be obtained from CMA.

ENVIRONMENTAL DEFENSE FUND

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TESTIMONY OF DR. MICHAEL OPPENHEIMER

before

THE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

U.S. SENATE

11 June 1986

Hearings on Ozone Depletion and The Greenhouse Effect

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INTRODUCTION

My name is Dr. Michael Oppenheimer. I am a senior scientist with the Environmental Defense Fund. My expertise is in the area of atmospheric physics and chemistry, and my research in recent years has focused on air pollution and acid rain. I am currently head of EDF's climate change project.

My testimony today will focus on climate change, a problem which, if unchecked, will come to dominate all others in its effect on the environment. The composition of our atmosphere, the earth's radiation balance and our climate, are changing due to human activity. The changes humans are bringing to the atmosphere will shortly begin to react on the biosphere. From the perspective of human history, these changes will be rapid and costly; and many will be highly undesirable. The viability of many ecosystems is at stake as is, some say, the viability of civilization as we know it. The changes may occur faster than our knowledge of them increases; yet, we currently know well how to limit these changes. Since the consequences of ignoring climate change will be severe, it is time for the U.S. government, along with governments of other nations, to come to grips with this problem.

We have begun an unintended experiment on the atmosphere and, eventually, the biosphere. As with all experiments, we know some of the questions to ask, but we will have limited insights into the answers until the results are in. Unfortunately, large consequences will have become inevitable by that time. On the other hand, this experiment can be altered while in progress to limit those consequences, even though this course requires action with only partial understanding. We cannot afford an undesirable outcome; we cannot afford to leave the experiment unchecked. It is time to develop policies to limit climate change.

Synopsis of Testimony

- Climate change by the early to mid 21st century will take us to climate conditions outside of previous human experience.

- Although the ecological effects of largescale climate change are little understood, there is no doubt that large changes will occur and some systems will simply disappear. These changes present a risk of unacceptable consequences to human civilization.

- Synergistic interactions among climate change, stratospheric ozone reduction, acid deposition and other pollutant stresses will amplify and accelerate the threat to the biosphere.

- Substantial climate change may already be "in the bank" so the time to consider policy to limit climate change is now. Actions to limit greenhouse gas emissions will slow climate change by keeping the infrared window open as much as possible, allowing our knowledge to expand faster than climate is changing.

- The process of international policy development to limit and adapt to climate change has begun. The U.S. government should aggressively encourage, support and participate in these activities. Governments can slow climate change by actions which are generally beneficial from other perspectives such as limiting dependence on fossil fuel and preserving and increasing forests.

- Research on climate change in general and its ecological consequences in particular must be rapidly expanded. Nothing is of higher priority than determining how fast we are narrowing the niche humans occupy in the natural system.

THE CHANGING CLIMATE

Owing to the limited state of knowledge on the nature of impending climate change, most investigation and discussion of this problem has focused on meteorological aspects, with some analysis of direct physical consequences such as sea level rise. But of gravest concern are the effects of these changes on the biosphere. Allow me to briefly summarize the nature of the impending climate change,[1,2] before proceeding to discuss its biological consequences.

The climate of the earth is determined by the balance between the rate at which the earth is heated by solar energy and the rate at which it is cooled by radiating heat into space. This balance is strongly affected by various components of the atmosphere which can act as a blanket and slow the outflow of radiating heat (by absorbing infrared or heat radiation). Such a slowdown can warm the planet. Among the natural atmospheric constituents capable of altering the radiation balance are water vapor, carbon dioxide and methane. Artificial substances, such as fluorocarbon compounds (which can also alter the earth's ultraviolet shield of ozone), can act similarly, even in minute quantities.

Recent atmospheric measurements reveal that the abundance of several of these chemicals, particularly carbon dioxide and methane, are increasing. The carbon dioxide increase is attributable to fossil fuel combustion, and to the destruction of forests, which converts carbon from organic forms into carbon dioxide. Fossil fuel "mining" and combustion is also responsible for some of the increases in methane, nitrous oxide and other "greenhouse" gases. Some of the increases are due to other anthropogenic activity (such as refrigeration, which releases fluorocarbons and agriculture, which releases some methane). Emissions of carbon dioxide and several other greenhouse gases are growing.

The effect of these anthropogenic activities on climate can be predicted with computer models. The picture painted by these studies is for an earth, within the next century, which is climatologically very different from the one we know.

Projected increases of carbon dioxide and other trace gases are predicted to increase the average global temperature by the middle of the next century by about 3 ± 1.5 °C over current values.[1,3] Excursions from current values are larger than average at the poles and smaller than average at the equator. Shifts in precipitation patterns can be expected to bring arid conditions to the mid latitude breadbasket areas while increasing precipitation in continental areas at more northerly latitudes. Sea levels will rise slowly at first, and more rapidly after the next century if major ice shelves destabilize and slip into the sea. Coastal flooding could become significant in already marginally useable terrain in places such as Bangladesh and coastal Louisiana, as early as the mid 21st century. The frequency of temperature extremes may increase much faster than the mean so that many more very hot days can be expected in Mid America within a few decades.

If fossil fuel use continues only at current rates for the next 100 years, marked climate changes will occur. However, if fossil fuel use and other activities which produce trace gaes continue to increase at current rates of change, the climate will be greatly altered in far less than 100 years.

In either case, if the changes in temperature and precipitation predicted by the atmospheric models occur, the effects on the global ecosystem will be substantial. Some coastal wetlands will disappear and there is no certainty of their re-creation further inland. Coastal habitation and other infrastructure will be destroyed in low-lying areas. In areas such as Bangladesh where the problem of limited arable land was made apparent by the recent cyclone, the population will be further compressed. In the developed world, agricultural productivity will decline in some areas of current high productivity and moderate rainfall, as they become arid. Whether other areas will become wet and fertile rapidly enough to avoid major dislocation is problematic. Entire ecosystems, such as those of the Arctic, may be eliminated.

On the other hand, some benefits may accrue from climate change. For instance, the moderation of the northern climate could allow increased habitation and cultivation in parts of Canada and the Soviet Union. Some crops may benefit from high temperature and carbon dioxide levels. No quantitative comparison has been made of the practicality or costs of preventive vs. adaptive strategies. Nor is such a comparison entirely feasible, as we cannot properly value global scale ecosystem loss.

A small scale preview of potential dislocating effects of climate change was evident in one short month last spring in three climate induced occurrences unrelated to greenhouse warming. Previously lush forests burned to the ground due to a sustained drought in Florida. The Northeastern U.S. suffered a sustained drought threatening urban populations with at least minor economic dislocations due to water shortage; large numbers of people died in a cyclone in Bangladesh which brought up the sea level a few feet. While sea level rise due to the greenhouse effect would be more gradual, the loss of agricultural land may be even more extensive and permanent.

Several important points should be made: the predicted warming would produce global mean temperatures warmer than any during human experience and the change in temperature exceeds temperature variations during recorded history. We will transcend human experience long before a CO_2 doubling occurs. Furthermore, weather events, such as successive high temperature days, will deviate from the past by larger amounts than will the mean. Systems sensitive to outliers will suffer accordingly.

Ecological Consequences

Little attention has focused on the consequences of climate change at the level of particular ecosystems. However, investigation of these consequences provides the key to understanding the degree to which climate change must be limited. The interactive web of dependencies in natural systems will be altered in ways which are not yet predictable. Those who argue that humans can slowly and relatively painlessly adapt to such changes speak with an unwarranted optimism. Civilization exists within a context of natural systems and there is reason to fear that such systems will not adapt to climate change in a manner tolerable for humans. It is enough to note that the relatively small natural temperature variations over the last 10,000 years have been accompanied by substantial changes in natural systems and extended impacts on civilization. With no action to limit change, the future holds much larger impacts.

Let me briefly describe just a few of the possible ecological consequences of climate change:

- changes in precipitation will decrease runoff in many areas; in combination with increased temperatures, these changes may doom many mid latitude forests;
- arctic ecosystems will shrink substantially;
- soil moisture reduction and forest decreases will enhance erosion in some areas;
- wetlands will disappear with sea level rise. Coastal development precludes re-creation in many areas. The consequences for fisheries in particular and marine life in general are uncertain.

But climate change is not occurring in a vacuum. Our natural systems are continuously suffering alteration due to various other stresses, including air pollution. In the future, these stresses will act synergistically with climate change. For instance:

- Urban smog will increase due to the combined effects of decreased stratospheric ozone (due to fluorocarbons) and increased temperature.[4]
- Enhanced oxidants, temperature and acid rain due to increasing sulfur dioxide and nitrogen emissions mean more stress on forests in industrial areas, where forests are already severely distressed. In fact, recent events in Central Europe where warm periods and air pollution are thought to have combined to severely disturb forests, may be a preview of the consequences of climate change. This interaction will reduce forest carbon storage and further accelerate climate change and soil erosion.
- Climate change occurring while soil microbes are stressed by increasing toxic metal, nitrogen and sulfur deposition could alter nutrient cycling rates.
- Aquatic systems will suffer increased acid stress from increased acid deposition at a time when flow will change significantly due to climate alterations.
- Increased ocean pollution combined with changes in circulation and wetland loss threaten ocean productivity.

This partial list strongly suggests that natural systems will change substantially. At very least, we will lose natural systems and biological diversity which we have fought so hard to protect. At worst, "human effects on atmospheric composition and the size and operations of the terrestrial ecosystems represent major excursions that may yet overwhelm the life support system crafted in nature over billions of years."[8]

Our knowledge is sufficient to demonstrate large potential risk, but our level of ignorance is very high. In such circumstances, prudence argues for four immediate actions:

- Slow the growth in emissions of greenhouse gases to slow climate change, through vigorous attention to end use efficiency in energy and materials use and through other measures;
- Act to preserve forests and support reforestation to protect the terrestrial carbon reservoir;
- Increase massively the support for research on ecological impacts of all of these insults, to allow our knowledge to change faster than the climate;
- Slow the alteration of forest ecosystems by reducing air pollution stresses.

What Government Can Do

The remoteness and scope of climate change has discouraged policy makers from coming to terms with its potential effects. The alternative courses available, prevention, adaptation, or some mixture of these approaches, all require the focused attention of governments, and international cooperation. With some climate change probably already occurring, remoteness is now an insufficient reason for inaction.

A fundamental characteristic of climate change is that the greenhouse gases are relatively non-local in nature. Due to atmospheric mixing, location of source is not related to climate effect for CO_2 and most other greenhouse gases. Thus, climate change limitation can only come through international cooperation on greenhouse gas limitation. However, the industrial nations of Europe and the United States have a unique lead role in such a cooperative venture, since they are the current source of the bulk of emissions. If those nations do not take a leadership role now, substantial climate change will become inevitable as Third World countries develop, and increase their greenhouse gas emissions.

Preventive strategies in particular, only can be accomplished internationally and within a context which will allow economic growth in underdeveloped nations. Adaptive strategies, which could involve migration and changes in food distribution and in infrastructue, also require international cooperative efforts. A conservative view of global ecosystems favors preventive strategies, but with some climate change inevitable (and perhaps already occurring), strategies which are broadly protective, focusing on climate change minimization but preparing for some adaptation, merit attention.

A successful approach to climate change policy should aim for an international accord on greenhouse gases. Such an accord will only develop when the scientific community presents a consistent, understandable scientific position which elaborates the scope of impending climate changes and their global ecological consequences. The development of such an accord provides the occasion to balance the virtues of the various strategies and determine a realistic degree of prevention through greenhouse gas limitation.

Movement toward such policy formation is already occurring at the international level. Following the meeting last October on climate change at Villach, Austria, the principles, WMO, ICSU, UNEP, have established a task force:[6/]

(i) to help ensure that appropriate agencies and bodies follow up the recommendations of Villach 1985;

(ii) to ensure periodic assessments are undertaken of the state of scientific understanding and its practical implications;

(iii) to provide advice on further mechanisms and actions required at the national or international levels;

(iv) to encourage research in developing countries to improve energy efficiency and conservation;

(v) as deemed necessary, consideration of a global convention.

With this task force taking the lead, various private sector organizations, including the Environmental Defense Fund and the Beijer Institute of the Royal Swedish Academy of Sciences, are working to move the international community to the determination of policy. A meeting of scientists and policy makers is planned for the summer of 1987 to accelerate this process. These efforts are supported in part by private American foundations.

The Environmental Defense Fund supports the development of a timetable for activities leading to a convention on greenhouse gases. These activities should include specific policy research projects, deliberations among scientists and policy makers at the international level, and the scheduling of activities to develop a convention by a specific date.

With activity already underway, the U.S. government should immediately:

- support international efforts to develop a greenhouse gas convention;
- develop policy alternatives for limiting greenhouse gases and protecting forests. Such policy development should include estimates of the costs of inaction;
- massively increase support for climate change research in general and ecological research in particular;
- push for meaningful limitations on fluorocarbon production in the context of the 1987 Convention;
- encourage actions internally which increase end use efficiency in energy and materials use;
- attend to the long overdue alleviation of other regional air pollution stresses, such as acid deposition and regional smog.

With regard to climate change, we cannot afford to just "let it happen". The costs of a non-policy will be enormous. Let us set out now to determine a reasonable course for greenhouse gas limitation before we are overtaken by the dire consequences of inaction. Otherwise, unacceptable levels of climate change may be "in the bank" before we even understand what we have wrought.

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May 29, 1986

Senator John M. Chafee
United States Senate
Committee on Environment and
Public Works
Washington, D.C. 20510

Dear Senator Chafee:

I regret that due to prior commitments I will not be able to attend the June 10-11, 1986 hearings on Environmental Pollution. Instead I enclose written testimony which I hope will be taken into consideration.

The thrust of my testimony is that the potential consequences of the buildup of greenhouse gases (CO_2, CH_4, freons, etc.) in our atmosphere are not being given adequate attention. While the impacts of this increase remain uncertain, there is no doubt in my mind that they will be of great importance to agriculture and wild life. Mankind must prepare to cope with negative aspects of these changes and to take advantage of the positive ones. The complexity of this task is enormous rivaling other major challenges confronting mankind (i.e. the development of a long term energy supply, the control and cure of cancer, etc.).

As for these other quests, the route to success is by no means clear. Unfortunately, the management of the DOE CO_2 program treats the greenhouse problem as an engineering task rather than as a profound scientific challenge. They think mainly in terms of short-term goals (which they refer to as deliverables) instead of building a long-term edifice of people and observations which will lead to the breakthroughs we so desperately need if we are to properly prepare ourselves for the environmental changes which will come over the next hundred or so years.

If progress is to be made, the responsibility for the program must be placed into the hands of a qualified scientific manager who will listen to the knowledgeable people in the field.

Sincerely,

W. S. Broecker
Professor of Geochemistry
Member National Academy of Science

WSB:ems
Enc.

Testimony to be presented before the Senate
Subcommittee on Environmental Pollution

June 10-11, 1986

Wallace S. Broecker

Professor of Geochemistry

Columbia University

Member National Academy of Sciences

In my estimation we currently lack the ability to reliably predict the consequences of the buildup of greenhouse gases in our atmosphere. Furthermore, at the current rate progress, this deficiency will remain well into the twenty-first century. Hence, many of the important consequences of the greenhouse buildup will be upon us before we are even partially prepared to cope with them. The reason this situation exists can be stated very simply. The problem is a damn tough one. It will certainly not be solved in a few years or even in a few decades. In fact, it may never be fully understood. Like cancer and military defense, a highly sophisticated long-term effort will have to be made if substantial progress is to be achieved. While society has accepted the reality of the situation regarding cancer and military defense, it has not come to grips with either the importance or complexity of the situation relating to future global climates. Certainly the Department of Energy which leads our nation's CO_2 program has yet to be enlightened. Its program is run as if it were routine engineering problem fully soluble on a ten-year time scale.

The CO_2, CH_4, freons, etc. that we are putting into the atmosphere will surely bring important changes in the environmental geography of our planet. While we are not likely to be able to prevent these changes, we can certainly better prepare ourselves to cope with them. However, if we are to succeed in developing response strategies, our attitudes and approach must be radically changed. The main problem with the present approach is that the underlying assumption is that we have most of the information we need and that the answers we seek are obtainable by massaging this information and making computer simulations capable of matching it. I maintain that the information in hand is inadequate and therefore attempts to squeeze valid predictions from it are destined to failure.

While the research during the last decade has not pushed us ahead very far in our ability to predict the consequences of the greenhouse buildup, it has dramatically shown us that the climatic system is interconnected in ways we have not seriously considered and that these interconnections lead to the possibility of responses about which we have not even dreamed. If this evidence is correct, it tells us that the "general circulation models" which are now used to predict the climatic impacts of a greenhouse buildup give us a very conservative view of how climate will change. The new evidence opens the possibility that rather than paralleling the smooth buildup of greenhouse gases, future climate changes may come in sharp steps and these steps may have complicated geographic patterns. If so, then we must begin to think in terms of climate surprises that may, without warning, cause shifts in temperature and rainfall pattern.

What I have just said is not found in most reports on the possible consequences of the greenhouse buildup. One reason is that these ideas are new. Another is that these ideas constitute a rather venturesome extrapolation of the evidence in hand. I am confident enough in them, however, to bring them to your attention as a serious possibility.

What is the evidence which leads me to these conclusions? It comes from the paleoclimatic record of the last 100,000 years. In particular, it comes from borings made through the Greenland ice cap. The ice record shows unequivocal evidence for sudden large jumps in climate. Analysis of this ice core evidence along with that from deep sea cores raised from the floor of the northern Atlantic Ocean and from cores obtained from European bogs, a consistent picture emerges which points toward the causal factor. This causal factor turns out to be changes in the mode of operation of the ocean's large scale circulation system. Thus, we have an indication of the possibility that when the climate system is provoked, the large-scale features of the Earth's great ocean-atmosphere heat engine may reorganize into a pattern more suitable to the new conditions. As these reorganizations alter the pattern and magnitude of heat transport within the ocean, they alter the climate on the adjacent continents.

Another interconnection about which we have recently become aware involves atmospheric chemistry and ocean biology. Associated with the sharp climate changes recorded in Greenland ice are jumps in the CO_2 content of the atmosphere. While the exact origin of these jumps is still the subject of debate, those working on the problem agree that it must involve major changes in the biogeochemial cycles occurring within the ocean and that these in turn stem from the reorganization in large scale ocean circulation pattern.

In my estimation, these new findings warn us that our view of the situation has been too simplistic. We have relied on simulations which, by their nature, prevent what may be the most bothersome aspects of the future climate response from occurring.

What should we do? My feeling is that we should launch efforts to understand those elements of the climate system which are now poorly understood. In order of importance, I would list the elements as follows:

1) The large scale circulation of the ocean.
2) The processes regulating soil moisture.
3) The processes responsible for cloud formation.
4) The role of global biogeochemical cycles in determining the trace gas content.
5) The processes regulating sea ice extent.

Of course, programs already exist in all these areas but in my estimation they will not bring the desired answers on the appropriate time scale. In each area we need major new observational programs to supply key data needed to develop a better physical understanding. In each area we need a cadre of young scientists with the appropriate training.

We also need to intensify our study of climate changes which have taken place over the last 100,000 years. Nature on her own has conducted climate experiments of large magnitude. The response of the system to these experiments is recorded in sediments and in ice. By thoughtful study of these records, we may be able to reveal modes of interaction among the various major elements of the climate system that would not otherwise come to mind. These hidden interactions are likely to carry the greatest threats.

Progress on this as well as other long term environmental questions (ozone, acid rain, water quality, etc.) is greatly impeded by the manner in which authority is distributed among federal agencies. Much of the money for research now lies in the hands of the Departments of Agriculture, Energy, and Environment. These agencies find it difficult to fund the long term programs which are required if we are to push forward our understanding of the systems we wish to protect. Instead, they fritter away large amounts of money on short term projects which do little to remove our basic ignorance. Furthermore, jealousies among the agencies greatly hinder attempts to put into action those long term programs which individual agencies deem worthy.

I see only one workable solution to this festering problem. Congress should create an entity charged with conducting the long term research projects which are essential to the wise management of the environment. This entity must be isolated from the immense political pressures which buffet the agencies responsible for environmental regulation. It must also have a mechanism to generate cooperative ventures with the agencies controlling the domains to be studied.

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June 1986

Honorable Members of Congress. The accelerating loss of life, arable land, and property now make it abundantly clear that the cooling world climate is the most important problem mankind has yet faced. It is appropriate to be deeply concerned about the nuclear problem. However, this problem is mediated by the will of people, and will can be persuaded by the survival need, reason, communication, and philosophy. Quite the opposite, the cooling climate is an inexhorable fact of nature. Cooling is the direct cause of the expansion of the world's deserts and the resulting famine, the increasing severity of both winter and summer temperatures, the longer winters, the increase in tornadoes and major storms -- in the thousands of percent during the last half century, the growing strength of the northerlies, and the dramatic increase in earthquakes and volcanism. Not originating in will or mediated by reason, nature's accelerating war on life deserves the highest priority and an immediate response.

The cooling is part of a cycle which has surely caused some 25 ice ages over the last 2.5 million years and possibly as many as 80 ice ages over the last eight million years. The community of climatological scientists has repeatedly delivered the consensus that the world is again cooling. If we are reasonable we can risk no other hypothesis but that the expansion of the arctic which we are experiencing is the start of the next ice age.

On the other hand is a group which claims that a greenhouse effect caused by increasing carbon dioxide and other greenhouse gases will override the cooling and, within the next half century, will cause a warming. The cooling theory is supported by the record and by paleoclimatological research. The warming theory is supported by the effects of greenhouse gases under certain restricted conditions, and by computer modelling from selected data. Death and destruction have reached the point where congress must quickly determine climatic reality and provide a technical solution. The time for action is well behind us.

The warmest climate of this interglacial period occurred over 6,000 years ago. The warmest peak of the century was in 1938, when conditions were succulent. However, by 1960 the cooling surfaces of the ocean were slowing evaporation to the atmosphere and the drier winds were bringing drought and famine to Sahelian-Sudanese Africa. The North American Desert was also expanding. In fuller perspective, the succulent Sahara region began its desertification process 4,500 years ago while the North American Desert began to take form 2,500 years ago. To blame overgrazing or farming practices is nonsense.

Another step in the cooling and desertification occurred in 1968-1973, following close after the event of the early '60s. The next period of desertification began only three years later, in 1976, and is still with us, apparently accelerating in severity. The millions of lives lost to famine and other cooling related phenomena, the loss of life supporting capacity of the land, and the hundreds of billions of dollars lost, attest to the cooling.

Most important is the acceleration which is evident in the expansion of the arctic. It can be claimed that a period of half a century is not a sufficient time from which to make long range predictions. However, this acceleration is to be anticipated from the history of the last 10,000 years, and indeed, from the history of millions of years. Mankind prepares for its intramural wars at enormous expense, despite the fact that much of the evidence by which we estimate the probabilities of war is created by the preparations themselves. However, the war now being waged on us by nature, the 100,000 year climate cycle, is known to us from scientific evidence and forceful perception. 1985 saw climate related deaths in the U.S. and in the world at a new record.

Drought, cold winters, hot summers, tornadoes, storms, severe northerlies, volcanism and earthquakes, and the competition for survival as migrations clash with southern populations may ultimately take half or more of the world population. With the start of year round full glacial snow cover life of the middle latitudes will attempt to relocate to the small land area of the tropics and subtropics. With global security obviously and seriously breeched and 14 years since the first formal warning from the climatological community we are still not armed for this war.

The first warning came from the 1972 conference of climatologists at Brown University, entitled "The Present Interglacial: How and When Will it End?"[1]. The consensus of this conference, made known to governments and the scientific community was that "In man's quest to utilize global resources, and to produce an adequate supply of food, global climate change constitutes a first order environmental hazard which must be thoroughly understood well in advance of the first global indications of deteriorating climate."

In 1974, from its conference in Bonn, the International Federation of Institutes for Advanced Study (IFIAS) issued the second warning to the governments[2], saying "... The studies of many scholars of climatic change attest that a new climatic pattern is now emerging... We believe that this climatic change poses a threat to the people of the world. The direction of the climatic change indicates major crop failures almost certainly within the decade. This, coinciding with a period of almost non-existent grain reserves, can be ignored only at the risk of great suffering and mass starvation... We urge the nations, individually and collectively, to plan and act to establish the technical, social, and political means to meet this challenge to peace and well-being. We feel that the need is great and the time is short."

In 1974 the CIA issued two reports, A Study of Climatological Research as it Pertains to Intelligence Problems, Office of Research and Development; and Potential Implications of Trends in World Population, Food Production, and Climate, Directorate of Intelligence, Office of Political Research. The former presented the findings and opinions of the climatological community -- that the world was cooling and the start of the next ice age was imminent. The latter concurred, stating "If the cooling continues for several decades there would almost certainly be an absolute shortage of food... There would be increasingly desperate attempts on the part of the powerful but hungry nations to get grain any way they could. Massive migrations, sometimes backed by force, would become a live issue and political and economic instability would be widespread... In the poor and powerless areas, population would have to drop to levels that could be supported. The population problem would have solved itself in the most unpleasant fashion."

In 1975 84 climatologists from ten countries, attending the First Miami Conference on Isotope Climatology and Paleoclimatology, chaired by Nobel laureate Willard Libby and the father of modern climatology, Cesare Emiliani[3], made available to government the following consensus: "1) Ice ages have been the normal condition during the last several million years, with temperate climates enduring only about 5% of the time... 2) Because the global food supply depends primarily on climate, current understanding of climate must be vastly improved in order to meet the challenge of tomorrow's food supply. We possess the methods and techniques to establish climate history and only a concerted effort is needed to do that."

In 1977, at the Washington convention of the American Geophysical Union, a member of the President's Council of Economic Advisors reviewed the potential impact of a (predicted) heavily coal burning economy on carbon dioxide and, thereby, on climate. Carrying the authority of the White House, Dr. William Nordhaus made it clear that government favored the carbon dioxide warming theory, although this was "not official policy."

Prior to 1977 a number of climatologists were publishing articles in the public media, predicting cooling and describing the changes which could be expected. After 1977 the majority opinion, cooling theory, became low key in the scientific media and a concerted popularization effort was launched by the warming theorists and supported by millions of dollars from the Department of Energy.

The committee on climatic change of the National Academy of Sciences, which had published Understanding Climatic Change: A Program for Action, in 1975, had dissappeared in 1977 and a new committee, on climate and energy, espousing warming theory, had appeared.

In 1976 the UN's World Meteorological Organization, after attempting to keep the issue hidden, was pressured into preparing the 1979 "Conference of Experts on Climate and Mankind". Few if any of the major cooling climatologists appeared at the Geneva conference. Nevertheless, by the end of the meeting there was a general consensus, according to writer Peter Collins of the journal Nature[4], "that the Earth is at the start of a potential cooling period of perhaps 10,000 to 20,000 years, possibly not an ice age in the sense of those recorded in geological time, but still a long term change...(and as quoted from an official working group report pertaining to gases being released to the atmosphere) that 'it is possible that some processes could lead to a cooling (rather than a warming as with CO_2) of the atmosphere'." The consensus released by each committee was hard fought, with signs of compromise.

A brief abstract of climatic history, taken from the scientific consensus, can provide a perspective on today's developing catastrophe. Of the original materials which fell together to create the Earth the radioactive materials immediately provided a significant proportion of the heat balance. However, today only about half of the original uranium is left to produce heat, and just over three quarters of the original thorium is estimated to be contributing heat to the planet. Thus if we assume a stable sun the planet has been growing colder since its beginning, 4.5 billion years ago.

On the scale of millions of years there are signs of catastrophic coolings caused by atmospheric dusts and aerosoles raised by collisions with astronomical objects or by volcanic erruptions. However, the age of ice began somewhere between 2.4 and eight million years ago, a more exact resolution probably being on the way. Certainly this cooling is due in part to the decay of the radioactives. The direct trigger of the ice ages is systematic -- the regular changes undergone by the Earth's elliptical orbit, its tilt, and its wobble.

On the scale of thousands of years the astronomical rhythm imposed on the climatic cycle is 100,000 years, about 90,000 years of ice and 10,000 years of temperate interglacial climate. Our interglacial period, the Holocene -- the cradle of civilization -- is now over 10,000 years old. It had reached its highest temperatures between six and seven thousand years ago, had cooled sufficiently to begin converting the green and succulent Sahara region to desert some 4,500 years ago -- and to begin developing the North American Desert some 2,500 years ago.

On the scale of years we find growing catastrophe striking the U.S. and much of the rest of the world with increasingly severe winters and hotter (droughtier) summers since 1976. These changes are accompanied by the increasing destructiveness of the northerlies (these may reach 200 miles per hour or so over extended periods during an ice age); an increase in tornadoes and hurricanes (of some thousands of percent since 1938); increasing floods caused by the El Niño phenomenon and snow melt; and a very significant increase in earthquakes and volcanism, directly related to the increasing snow cover and its seasonal changes. Weather related deaths have increased sharply since 1976, the new record being set in 1985 in the U.S. and globally. Perhaps the most significant indicator of the foreseeable future is the degradation of farmland in the North American grain region. In 1976 drought was responsible for over a 20% loss of the North American wheat crop, some 50% of the corn crop, and nearly all of the soybean crop. North Dakota, Minnesota, and a belt south to the Texas gulf coast have historically been dryfarmed. In 1976 the North American Desert expanded into this region. Wells were drilled into the famous Ogallala Aquifer and other ground waters and farming became dependent on irrigation. Today we find that even the Ogallala Aquifer is limited and we are looking at the Great Lakes and a huge irrigation network.

We have observed, over the last decade, that cold winter is followed by hot summer. This has caused problems in reporting the climatic change. Whereas it seemed sufficient to average the year's temperatures into a "mean annual temperature" this is no longer a true manner by which to describe the change -- simply because a cold winter and a hot summer cancel each other out and provide a moderate year when they are averaged. Nothing is more misleading and climatologists must now average the cold and warm seasons separately. By this manner they are able to conform their description of climate to what is happening, that the colder ocean currents carry arctic cold into their circulation patterns and, thereby, into the regions where weather for the middle lattitudes is made. The colder ocean surface slows the rate of evaporation. The decrease in clouds increases the solar energy reaching the land mass, the loss of soil moisture reduces the evaporative cooling of the ground, and the heat produced makes for high pressure which, in turn, produces even more heat.

Thus the hot droughty summers are caused by the cooling. The colder the preceding winter the more drought and heat can be anticipated in the summer. The major Pacific ocean current in the northern hemisphere requires about six months to transfer arctic cold to the western Pacific where U.S. summer weather is made. Thus the heavy snows which were produced in the northern U.S. on 2 September 1975 were part of the causal chain which produced drought and wildfires in 11 states from the Great Lakes to the southeast on 31 March 1986.

The general circulation pattern, by which warm air rises to high altitudes above the equatorial zone, is carried to the (growing) arctic zone where it cools and sinks, and flows back to the equatorial zone, is of enormous import for cooling. During the winter the general circulation pattern carries water to the higher latitudes where it precipitates as snow cover. Two mechanisms are now contribiting to the speed and cooling effectiveness of this atmospheric engine: 1) As the arctic grows toward the equator the engine speeds up. More water is carried to the north and the returning winds on the surface, the northerlies, are colder and stronger (and their damage to agriculture and structures is increasing). 2) As carbon dioxide increases it warms the equatorial zone, both evaporating more water and speeding up the engine which carries the water north -- thereby contributing to the snow cover, which in turn manufactures more cold. Paleoclimatology now tells us that a significant increase of carbon dioxide, caused by the killing of vegetation by drought and cold, ushered in the last ice age.

Another manner in which increasing carbon dioxide contributes to the cooling is by intercepting a portion of the sun's energy before it reaches the Earth's surface. Of greater interest yet is that the carbon dioxide screens out the near-infrared rays from the solar spectrum, these being the specific wavelengths which are absorbed by snow and ice to initiate melting. Thus, on a planet with considerable areas of snow and ice carbon dioxide cools rather than warms.

As the expansion of the arctic puts the influences of the arctic and equatorial zones in intimate contact, weather becomes more violent. Tornadoes and major cyclonic storms have increased by some thousands of percent since the latest increment of cooling began in 1939. These events made 1985 the greatest year on record for weather related deaths. Increasing episodes of wind-shear also contribute to weather related deaths although aircraft crashes may be counted under a different category.

Of increasing importance, and possibly of penultimate danger is the mechanism whereby increasing snow cover and the heavier column of air above it depress the Earth's surface beneath it. In a closed hydraulic system such as the plastic and fluid Earth, this depression causes an outward distension of the rest of the planet. This tends to ease the pressure between the walls of earthquake faults and to increase the upward dynamics in volcanos and vents. The increased snow cover thereby increases, also, the number of earthquakes, volcanic erruptions, and releases of heat from undersea vents. Of great import is the fact of increasing volcanism. Should volcanic erruptions include some two or four erruptions of the Tambora or El Chichon types within a four or five year period the sun will be occluded sufficiently for the planet to fall precipitously into the ice age. Should this happen there is little which can be done for the civilization and for the majority of the planet's land dwellers. This scenario, called the snowblitz by members of the climatological community is reason enough for an all-out emergency effort to halt the cooling.

Early in the century we were aware of a localized phenomenon which halted an upwelling at the Peruvian coast and periodically destroyed the anchovy fishery. This was related to a cessation of the trade wind pattern and the movement of a resident high pressure area from the Pacific to the Indian Ocean (the southern oscillation). This phenomenon lasted some few weeks often ending close to Christmas, and was thereby named El Niño. In 1982-1984 the middle latitudes were subjected to warm, humid, and rainy weather which was also called El Niño. There is a controversy as to what causes the warm ocean surfaces of the phenomenon but there is good observation to show that they may be related to increased snow cover and, generally, with the cooling. Thus we can do little damage if we cast another El Niño hypothesis on the pile. Undersea vents releasing geological heat have now been discovered in many places, usually on the edges of tectonic plates. Should the periodic activities of these vents cause the warm ocean surfaces of the El Niño we would have a new perspective -- that the El Niño is a feedback to the cooling. A positive feedback if the precipitation increases the snow cover and a negative feedback if it ameliorates the drought, darkens the land with vegetation, and thereby contributes some warming. The summer of 1984 was drought but it was distinguished by a plume of high humidity which originated in the Caribbean and moved to the north and west, against the usual weather pattern, to affect the southwestern U.S.. Our hypothesis is that this phenomenon was caused by the release of geological heat into the Caribbean.

The Earth's orbital position states that the next ice age is due, perhaps past due. Part of the process has been a 6,000 year period of cooling which now seems to be accelerating. This conclusion is supported by the increasing global desertification and the increase in the variety of disastrous events discussed in prior paragraphs. A minority of the climatological community has actively supported a greenhouse warming theory but physical evidence and theory emphatically supports the cooling theory. The cooling has now become catastrophic on a major scale, security considerations absolutely require that mankind prepare and utilize its technology against the war being made on us by nature, and time leaves us no alternative but to act now. This belated action, if instantaneous, can still do no more than cut our future losses of life and property.

Perhaps the most feasible defense is the Global Climate Space Reflector System, some thousands of thin film reflectors of aluminized plastic on very light, flexible, structures, manueverable via small remote-controlled solar ion jets. Some 1.5 million square kilometres of reflectors, orbiting over the day-night terminator would provide the .1% solar energy to the Earth's surface to replace that which is lost to the planet's orbital change. Each reflector would rotate so as to avoid beaming energy into the tropical zone. Such a system would last 60-100 years. Mass production would place its cost at $100-300 billion amortized over the life of the system.

Another method would be to float reflective material on the tropical waters, so as to cool them, while darkening the surfaces of middle and high lattitude waters so as to keep solar energy from distributing itself into the depths. This method would decrease the northern snow cover while darkening the middle latitudes with vegetation to warm the planet. Calculation may show that this can reverse the cooling process. If so there will still be the problem of marine fouling and corrosion of the materials used, and the problem of interference with shipping.

The direct darkening of light colored deserts and snow cover with pigment would be very costly due to the large amount of material, applied constantly to cope with wind, washing, weathering, and snow melt.

Dry farming in the U.S. is dwindling. The use of the Great Lakes and an enormous irrigation network may wreck the U.S. economy and raise the cost of food too high. Thus a climate resistant and inexpensive new food source must be found. An analysis of spirulina algae by the UN Food and Agriculture Organization shows what may be the single most nutritious food base known, lacking only in vitamin C. An automated solar powered sea water pond will double the amount of spirulina every three days, producing a superior nutrition at thousands of times per acre more than soybean.

We have learned to prepare for, and wage, wars of questionable purpose over this last 10,000 years. To back away from civilization's ultimate and most valid war would raise questions of motive, today and in history.

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